Study and Design of MPEG-2 Transport Stream Multiplexer of Private Data Broadcast

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Study and Design of MPEG 2 Transport Stream Multiplexer for Private Data Broadcast

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Certificate

This is to certify that the work contained in this thesis entitled *Study and Design of MPEG-2 Transport Stream Multiplexer for Private Data Broadcast* by D.V.S.N. Murty has been carried out under my supervision and that this work has not been submitted else where for a degree.

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K.R. Srivathsan,
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To

my pedanannagaru (uncle)

Sri D V Siva Rao

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D V S N MURTY

Abstract

Digital TV and audio broadcasts are poised to replace the current analog TV broadcast for entertainment news and other one way broadcast applications Broadcast channels provide high quality with good SNR at affordable costs Digital TV provides two new opportunities besides current broadcast services first emerging services based on video on demand and second data broadcast related applications Data broadcasting from a central server site with low band width interactive channels to clients provides new broadcast applications in the form of hybrid network to bring Internet and Electronic commerce to homes at affordable cost

In this thesis a review of MPEG 2 standard for video audio and private data compression and multiplexing is first carried out Then a detailed study on the issues involved in the embedding of private data over the MPEG 2 Transport Stream multiplexing is presented Finally some measurements of the proposed private data multiplexing in the Transport Stream are presented based on trial implementation over a software MPEG 2 Transport Stream multiplexer

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Glossary

1 **access unit** An MPEG 2 compressed picture or audio

2 **bit rate** The rate at which the compressed bit stream is delivered from the channel to the input of a decoder

3 **channel** A digital medium that stores or transports an ISO/IEC 13818 stream

4 **constant bit rate** Operation where the bit rate is constant from start to finish of the compressed bit stream

5 **elementary stream** A generic term for one os the coded video coded audio or other coded bit stream in PES packets One elementary stream is carried in a sequence of PES packets with one and only one stream id

6 **packet identifier PID** A unique integer value used to associate elementary streams of a program in a single or multi program Transport Stream

7 **PES Stream** A PES stream consists of PES packets all of whose payloads consist of data from a single elementary stream and all of which have the same stream_id

8 **Private data** Non video and non audio data that can be multiplexed along with video and audio data

9 **presentation unit** A decoded Audio Access unit or a decoded picture

10 **program** A program is a collection of program elements may be elementary streams Program elements need not have any defined time base those that do have a common time base are intended for synchronized presentation

11 **Program Clock Reference (PCR)** A time stamp in the Transport Stream from which decoder timing is derived

12 **Program element** A generic term for one of the elementary streams or other data streams that may have included in a program

13 **Program Specific Information (PSI)** PSI consists of normative data which is necessary for the demultiplexing of Transport Streams and the successful regeneration of programs

14 **Program Stream** One or more elementary streams that share a common time base combined into a single stream

15 **reserved** The term reseived when used in the clauses defining the coded bit strenm indicates that the value may be used in the futuie for ISO defined extensions Unless otherwise specified all ieserved bits sl all be set to 1

16 **system tirget decoder (STD)** A hypothetical reference model of a decoding piocess used to desciibe the semantics of an ISO/IEC 13818 multiplexed bit stream

Chapter 1

Introduction

1 1 Convergence of Different Media

The LAN technologies and Internet have brought communications and computing together and offer us several networked services Common among these services are *email ftp WWW and telnet* Because of the expansion of Internet several multimedia and real time applications on Internet such as Java applets based MMI (Multimedia Information) browsing Internet phone video conferencing etc are emerging Internet is also growing fast as a medium for electronic commerce providing interactive shopping financial services etc

At the same time the existing telecom structure is not able to support the increasing demands from the emerging technologies and is switching over to newer technologies Asynchronous Transfer Mode (ATM) Integrated Services Digital Network (ISDN) and Asymmetrical Digital Subscriber Line (ADSL) are some of the technologies which offer higher bandwidths higher speeds symmetric or asymmetric channels and are suitable for applications such as video telephony where not only voice but also picture information need to be transferred over the channels

On the other hand Terrestrial Broadcasting which has served analog television for many decades is also becoming digital The digitization is being led by the projects like Digital Video Broadcasting (DVB) in Europe and Grand Alliance (GA) in USA The aim of these projects is to increase the number of channels available to the viewers by many folds These projects have adopted MPEG 2 (Moving Pictures

Experts Group 2) as its standard for compression of video and audio data and for multiplexing the compressed audio and video data streams

Efforts are also going in a new kind of television called Interactive Television (ITV). This is a new form of digital consumer multimedia service that can give viewers much greater control over the content of the program than is possible with conventional analog television. The aim of this kind of television is to provide services like video on demand, multimedia information retrieval, distance education, home shopping and multi player multi location video games and so forth

Digital broadcasting technology and Internet are leading to the merging of the computers and the TVs into a new system mean for entertainment and work at the same time

1.2 Need to Transmit Private Data over Broadcast Channels

The convergence of the Internet with TV will lead to a concept called hybrid network. Most of the applications of the Interactive TV have higher BW requirements in one direction and a much lower BW required in the reverse direction. For example in case of the video on demand or digital library access, subscribers send a request to the multimedia server through either ordinary telephone lines or some other low BW links and in the reverse direction large files are downloaded from the server as shown in the Fig 1.1

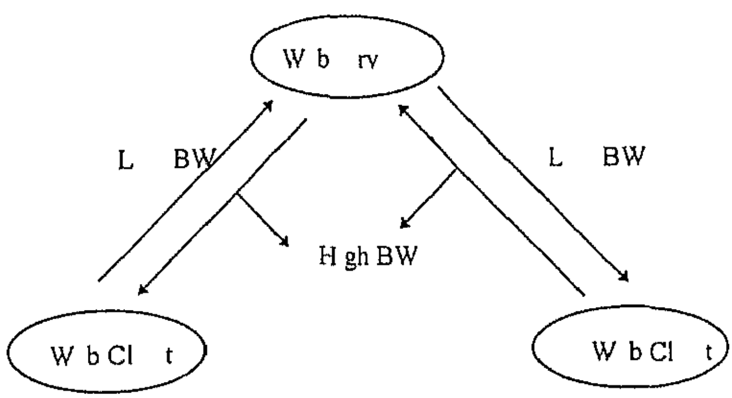


Fig 1.1 Asymmetric BW requirement of Web based applications

This large bandwidth required in the reverse direction can be achieved by dedicated lines but this would be costly and wasteful as well. As an alternative, existing TV

b oadcast cl annels c ı b used to tıansmıt th se laıge volumes of data ıth a s ıfi ant d r as ın th ost h co ı pared to dedı ated lınks

1 3 How MPEG 2 Suppoıts Pııvate Data Broadcast?

MPEG 2 as descrıbed ın later hapters has a pıov s on to multıplex ıdeo audıo and pıı ate data nto a sı ı le stream called T ansport Stream (TS) and tıansmıt that st eam throı h eı or pıon e ıvıronments l ke b oad ast chann ls v th mı ımum transmıssıon erroıs The ı ıternatıonal standaıd ISO/IEC 13818 1 (systems) detın s the syntax for multıplexıng MPEG 2 compressed aud o vıdeo and prıvate data a ıd to convey the synchronızatıon of audıo/vıdeo sıgnals [1]

Objectıve

The objectı e of thıs thesıs ıs to study and desıgn the Transport Stream multıplexın and to see how prıvate data can be sent over the broadcast channels along wıth the oıdınary televısıon pıograms Here the word *pı vate* has been used ın a bıoad sense HTML documents IP packets multımedıa ınformatıon teletext a e some of the forms of prıvate data The aım ıs to buıld a data broadcastıng servıce over the hybrıd network usıng MPEG 2 at the transport level

Woık done ın thıs area

Most of the work done ın thıs area ıs under the proprıetary rıghts of the concerned or an zatıons Interactıve TV Web TV Internet phone vıdeo on demand aıe some the commercıal servıces already avaılable ın the U S Europe and Japan Products such as IRD (Inte rated Receıver Decoder) Transport Stream multıplexer etc aıe avaılable ın the form of VLSI cırcuıts But beıng proprıetary ıt ıs useful only for commercıal puıposes At the academıc level two students have done some sı nıficant ork ın thıs aıea One ıs the thesıs work done by Mr Chrıstos Tryfonas of Unıversıty of Calıfoınıa tıtled MPEG 2 Transport over ATM Networks [6] The otheı ıs the thesıs woık done by Mr Luı ı Atzorı of Unıversıty of Ca harı (Italy) tıtled Conveyın Multımedıa Servıces wıthın the Transport Stream MPEG 2

1 4 Oı ganız1tıon of thıs Thesıs

Thıs thesıs ıs organızed ınto 5 cl apte s The second chapter presents an o ervıe\ of MPEG compressıon techn ques 1nd dıfferent kınds of multıple\ıng st ategıes used ın MPEG 2 to transmıt compressed data alo ı wıth the prıvate data In Chapter 3 a detaıled descrıptıon of Tra spo t Strean multıplexın has been p ese ıted Ch1ptei 4 concentrates o ı ımplement1tıon ıss es of a Transport St eam multıple\ r and the results we obtaıned ın o ır st ıdıes Chapt 5 concludes the thesıs wıth the conclusıons of our work and the scope of the future \ork

Chapter 2

MPEG 2 A Standaı d for Audıo, Vıdeo, and Prıvate Data

2 1 Introductıon

Dı ıtal compressıon technıques have bee ı tradıtıonally used to reduce the amount of data stoıage capacıty needed to save lırge files ın computers Foı the past decade the global Telecom ınd stry has also been usıng compressıon technıques to reduce the bandwıdth and consequentl) the cost requıred fo provıd n narrow ba ıd telephone cırcuıts Sınce late 80s communıcatıon engıneers began developın hıgh capacıty very laıge scale ıntegrated cırcuıts (VLSICs) and sophıstıcated softwıre routınes that could compı ess hıgh bandwıdth real tıme data such as vıdeo

Dı ıtal Televısıon and need for compressıon

A conventıonal PAL vıdeo sıg ıal contaıns 6?5 lınes per ındıvıdual ıma e or frame A sın le fra ne of conventıonal analog vıdeo ıs composed of 174 000 pıcture elements or pıxels more than 4 mıllıons pıxels are beıng sent to the televısıon screen eıch second Dıgıtal televısıon transmıssıon systems convert the vısual and audıo ınformatıon ınto stıeıms of bınary dıgıts or bıts A resoulutıon of 32bıts per pıxel are needed to dı ıtıze ı sıngle color vıdeo s ınal Thıs results ın a data rate of 128Mbıt/s A 128 Mbıt/s dıgıtal sıgnal would fill an entıe satellıte tıansponder to capacıty To allow multıple dıgıtal TV sıgnals to share a sıngle transponder bandwıdth the dıgıtal televısıon sı nals have to use compıessıon technıques wıth a compressıon ratıo of moıe than ?0 1

The advantages of the dı ıtal representıtıon of a sıgnal agaınst the analog one are

a) Increase ın the sıgnal qualıty and ıobustness to noıse

b) Fıd lıty of regeneıatıon

c) Effıcıent stoıage and ıet ıeval of TV sı nals for edıt n and transmıssıon

d) Rındom a cess of stored dıta

e) Dıgıtal bıoadcast ng technology has enabled the meıgın of comput rs and TVs to etheı Useıs cın use the same equıpment foı both entertaınment as well as for work The same equıp nent that decodes ınd shows entertaınment p o rams(vıdeo/movıe oı de ı d mov e l stıng ames) vould also become the basıs for ınte actıve transa tıonal and nformatıon s rvı s(dıstant educatıon programs bank opeıatıons remote databases) as well as a tool to access socıally useful ınformatıon (telemedıcıne news on demand etc) In such a wa dı ıtal broadcastıng ıs the drıvıng force for both the ıntegratıon of dı erse medıa and the extensıon of computıng ınto our daıly lıfe

2 2 The Movıng Pıctures Experts Group

In 1988 the Internatıonal Standards Organızatıon (ISO) of the Telecommunıcatıons Unıon establıshed the Movıng Pıctures Experts Group (MPEG) to a ree on ınternatıonally recognızed voıld wıde standard for the compressed repıesentatıon of vıdeo fılm graphıc text and audıo materıals The commıttee s goals were to develop a ıelatıvely sımple ınexpensıve and flexıble standard that put most of the complex functıons at the transmıtter rather than the receıver

MPEG 1

In 1991 the MPEG 1 standard was ıntroduced to handle the compressed dıgıtal representıtıon of non vıdeo souıces of multımedıa data MPEG 1 could be adapted for the encodıng/compressıon and transmıssıon of vıdeo sıgnals as lon as the vıdeo mateıial was fiıst conv e ted from the orıgınal ınterlaced mode to a progressıvely scanned format Thıs standard was aımed for applıcatıons such as stora e and retrıeval of multımedıa dıta on dı ıtal stora e medıa wıth a target bıt rate upto about 2Mbıt/s

MPEG 2

Lateı the scope of the MPEG group vas extended to provıde appropriate MPEG 2 vıdeo and ıssocıated audıo compressıon al orıthms for a v ıde range of

audio visual applications at a substant ally h le bit rates vhi h were not suc ssfully cove d or envisa ed by tl e MPEG 1 tandard Specificallv MPEG 2 was iven the chaiter to prov de video quality i ot lo ver tha i NTSC/PAL and up to CCIR 601 quality ith bit iates taigeted betwee 4 and 10 Mbit/s Emergin applications si ch as digital able TV distribution net vo ked database er ices a asynchronous tiansfer mode (ATM) digital video tape recoider (VTR) appli ations and satellite and teriestiial di ital broadcasting distiib tion vere seen to be iefit from the increased quality expected to result fiom th emer ing MPEG 2 standard This standard was released i i 1994

The MPEG 1 and MPEG 2 video compression techniques developed and standaidized by the MPEG group have developed into important and successful audio and video codin standaids world wide with an increasing number of pioducts becoming ava lable in the market One key factor for the si ccess is the gen ric structure of the MPEG standaids supporting a vide ran e of applications and application specific parameteis To support the vide range of applications profiles a diversity of input parameters including flexible picture size and frame rate can be specified by the user Also the MPEG group only standardized the decoder structures and the bit stieam formats Thus the manufacturers could increase the coding efficiency (i e video quality at a given b t rate) by developing innovative encoder algorithms even after the standards were finalized

MPEG 4

Anticipating the rapid convergence of telecommunications computer and TV/film industries the MPEG group officially initiated a new MPEG 4 standardization phase in 1994 MPEG 4 standardizes algoiithms and tools for coding and flexible repiesentation of audio visual data to meet the challen es of future multimedia applications and applications enviionments In particular MPEG 4 addresses the need foi universal accessibility and robustness in error prone environments hi h interactive functionality coding of natural and synthetic data as well as high compression efficiency MPEG 4 video standard targeted a bit rate of 5 64Kbit/s for mobile or public switched telephone network (PSTN) video applications and up to 4 Mbit/s for TV/film applications The release of the MPEG 4 International Standard is taigeted for Novembei 1998

2.3. Digital Video Broadcasting and MPEG-2

The next generation of TV signal broadcast standards is based on digital data compression and digital data transmission. The success of the MPEG-2 standards, led the Broadcast Engineering community to steer the standardisation of Digital TV around MPEG. The aim of the standardisation process was to provide for both higher image quality and better bandwidth utilization than classical analog color TV broadcasting signals such as PAS, NTSC, and SECAM.

In January 1995, the Digital Video Broadcasting (DVB) project originated by the European Broadcasting Union (EBU) has published a set of formal standards which define the new digital video broadcast system. A list of this is given in Appendix C. They specify the following functions: Format selection, Video coding, Audio coding, Transport and Transmission. These DVB standards are the technical basis for implementing digital TV transmission in Europe, Asia, Australia, and many other regions of the world. In the United States, a Grand Alliance has been formed by proponents of digital HDTV systems. The planned system is a digital simulcast with the current analog NTSC transmission. The goal of the Grand Alliance is to introduce an ATV (advanced television) terrestrial transmission standard for the United States. A simplified block diagram of a DVB receiver is shown in the following Fig. 2.1.

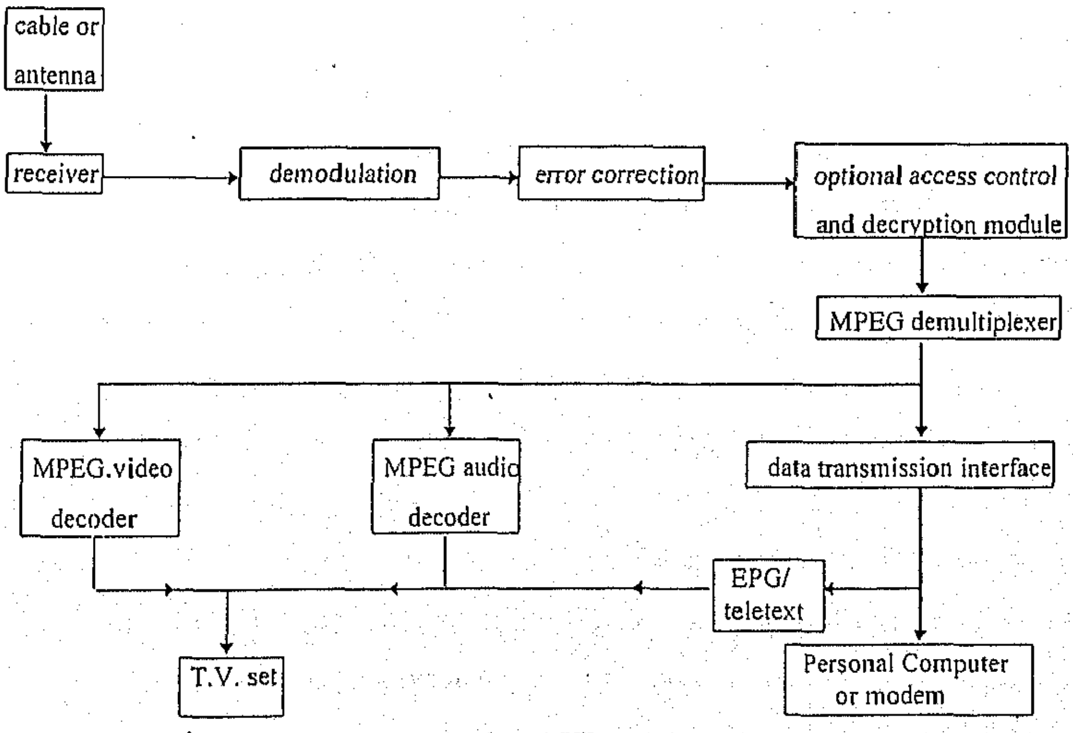


Fig. 2.1 DVB receiver

Whil th initial focus of the DVB project as deliverv of dig tal v deo to s t top converters these standards are broad enough to cover any form of hi h speed digital bioadcasting in luding software electronic ne vspapers Internet Protocol (IP) stiei ns or Web pages Conditional acc ss is one of the main featu es of tl e DVB streams The compression technique used by the DVB standaid is the MEPG ? algorithm MPEG ? is an audio/video compiession al o thm optimized for broadcast qu ility transmission up to HDTV quality The list of MPEG 2 sta dards (ISO/IEC 13818) is given in Appendix *A*

2 4 Brief Description of MPEG Compression Techniques

i) *Video Compress on*

MPEG compression is a complished by four basic t chn qu s pre piocessin tempoial prediction motion compensation quantization coding Pre processin filters out non essential visual information from the video signal information that is difficult to encode but not an important component of human visual perception Motion compensation takes advantage of the fact that video sequences are most often highly correlated in time Each frame in any given sequence may be similar to the preceding and the following frame

The digital video encoder scans subsections within each frame called *maci o blocks* and identifies which ones will not change position from one frame to the next The encoder also identifies predictor macro blocks while noting their position and direction of motion Only relatively small difference called the *mot o compe sated i esidual* between each predictor block and the affe ted current block is transmitted to the receiver The receiver decoder stores the information that does not change from frame to fiame in its buffer memory and uses it periodically to fill in the blanks

A mathematical algorithm called the Discrete Cosine Transform (DCT) reor anizes the residual difference between fiame from a spatial domain into an equivalent series of coefficient numbers in a frequency domain that can be more quickly tiansmitted Quantization coding converts these sets of coefficient numbers into moie compact iepresentative numbers The en oder refers to an internal index of *code book* of possible iepresentative numbers from which it selects the code word that best matches each set of coefficients Quantization codin also rounds off all

coefficient values, within a certain range of limits, to the same value. Although this results in an approximation of the original signal, it is close enough to the original to be accepted for most viewing applications. A simplified block diagram of MPEG-2 video decoder is shown in the following Fig. 2.2.

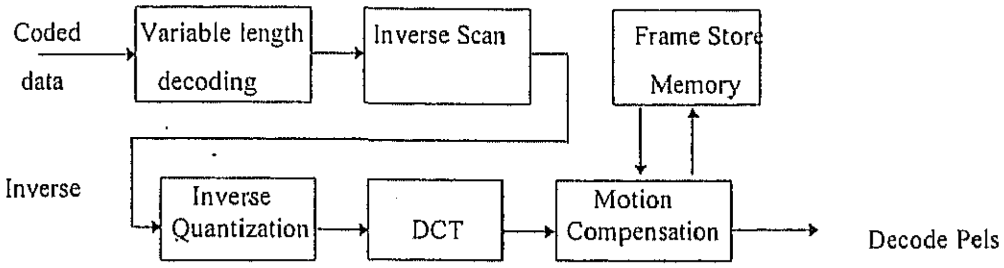


Fig. 2.2 Simplified Video Decoding Process

b) Audio Compression:

The main objective of audio compression is to represent an audio source with as few bits as possible, preserving the level of quality as perceived by the human ear. The ISO/IEC MPEG-2 Layer II encoding uses a sub-band representation of the audio signal in order to take advantage of the frequency masking properties of the human hearing system. The frequency spectrum of the audio signal is separated into sub-bands by the use of a sub-band or transform filter bank. This results in a representation of the audio signal by sub-band samples.

The sub-band signals may be quantized because the resulting quantization noise will be at a similar frequency, and relatively low signal to noise ratios (SNRs) are acceptable due to psychoacoustic phenomenon of masking. A psychoacoustic model of human hearing determines what actual SNR is acceptable in each sub-band. A bit allocation operation distributes the available bits among the sub-bands in accordance with the required SNR. The sub-band values are quantized to the precision indicated by the bit allocation operation and formatted into the audio elementary stream.

The selection of an appropriate audio source coding schemes for different applications like broadcasting and multimedia is of vital importance and should be considered carefully from a number of view points. MPEG defines three coding schemes namely Layer I, Layer II, and Layer III whose complexity increases in the

given order MPEG ? adopts Layeı II encod ng scheme as ıts audıo eı cod ı standard Thıs ıs a multıchannel a dıo e ıcodın cheme

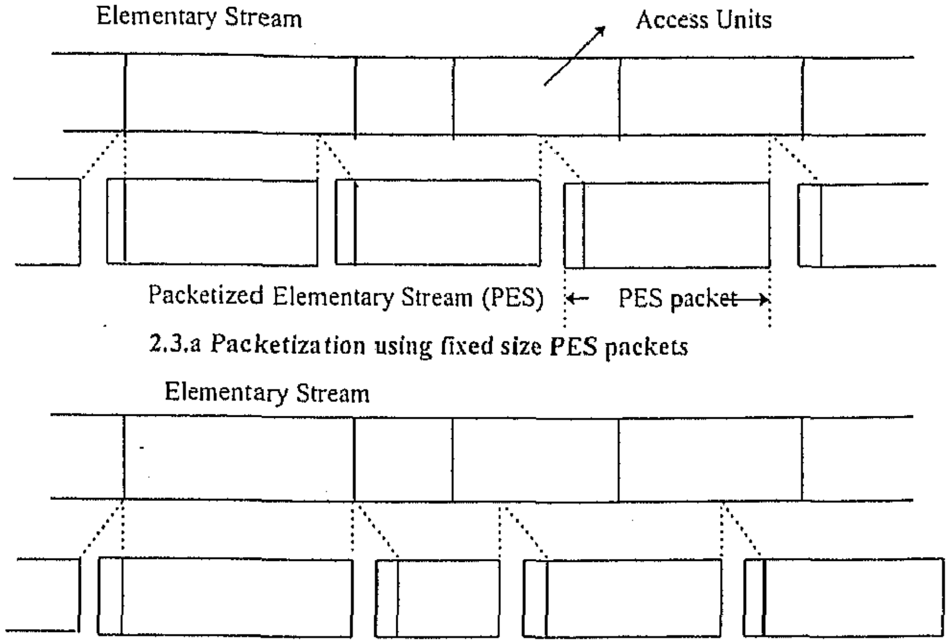
Bes des aı dıo and vıdeo codıng comp s ıon the DVB standards specıf the tıansport mechanısm as MEPG ? Syste ns codın The MPEG 2 TS a method of combınıng or *ı nutıpl ıng* multıple vıdeo audıo and pııvıte data streams togetheı The DVB standaıds then add other specıfıcatıons some medıa ındependent and some unıque to a partıculır medıa (lıke satellıte l nks) to specıfy the recomme ıded ombınatıons of technıcal parımete s such ıs modulatıon nd forward error co ect on codıng to ınsure ınteroperabılıty of products

2 5 Multıplexınᵍ of Audıo Vıdeo and Prıvate data

The MPEG ? systems layer (ISO/IEC 1 818 1 [1]) addresses the combınıng of one or more elementary streams (MPEG ? compressed vıdeo and audıo streams) of vıdeo and audıo as well as uncompressed prı ate data ınto a sın le or multıple streams whıch are suıtable for storage or transmıssıon Systems codıng follows the syntactıcal and semantıc rules ımposed by thıs specıfıcatıon and provıdes ınformatıon to enable synchronızed decodın at decoder buffers over a wıde range of retıeval or receıpt condıtıons

Systems codıng can be carrıed out ın two dıfferent ways the *Program Stı eam* and the *TS*

Pro ram Strec m Thıs ıs a multıplexıng approach to multıplex one or more elementary streams (compressed vıdeo and audıo stıeams) of a sıngle program (ı e elemenatry streams wıth a common tıme reference) ınto a sın le stream In the fırst sta e of the multıplexıng the data from elementarı streams are packetızed as shown ın Fıg 2 3 These packets are called *PES (Packetı ed Elementary Stı eam) packets* These PES pıckets consısts of a PES header followed by packet data (whıch ıs taken from elementaıy streams) These PES packets ın a second stage are organızed ın *packs* A pack consısts of a pack header and ıs followed by ıarıable number of PES packets A Program Streım be ıns wıth ı system header that mıy optıonally be repeated Thıs system heıder carrıes a summıry of the system parameters defıned ın the stream A detııled descııptıon of Progrım Stream cın be found ın [1] The



2.3.a Packetization using fixed size PES packets

2.3.b Packetization using variable size PES packets

Fig.2.3 Generation of a PES from an elementary stream

Program Stream approach is used when requirement for compatibility with MPEG-1 is stipulated.

TS: This is a multiplexing approach to multiplex video, audio elementary streams along with private data streams. In the first stage of the multiplexing the video, audio elmentary streams and data streams are packetized. These resulting packets are called *PES (Packetised Elementary Stream) packets.* In the second stage of the multiplexing the PES packets are put in the payload portion of Transport packets. The header portion of the Transport Stream (TS) packets are specified by the ISO/IEC 13818-1

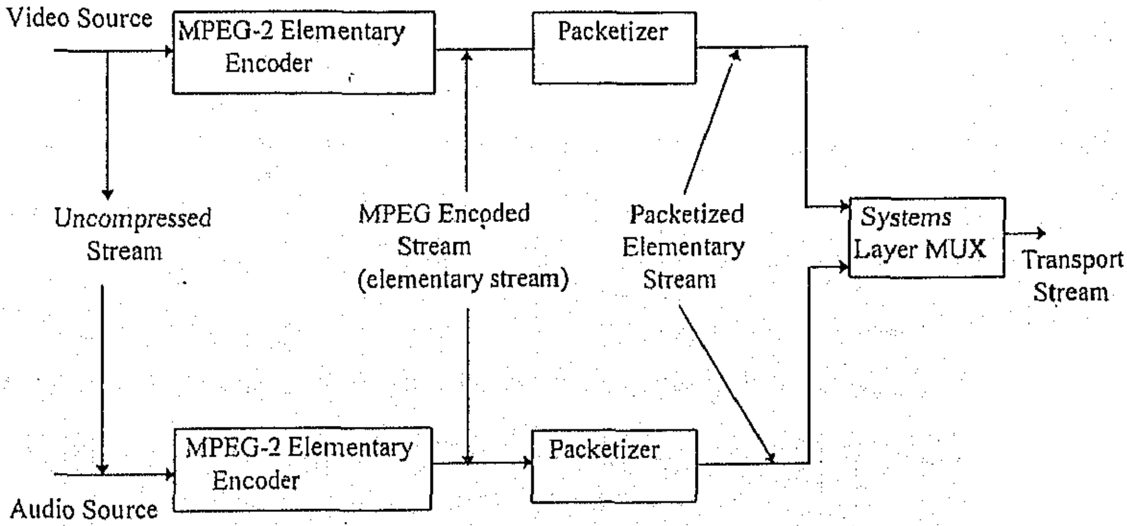


Fig. 2.4 Simplified overview of Systems layer (TS case)

st nda d [1] Eɿch TS packet cons sts ot 188 bytes out of wl ı h 4 bytes a e allocat d tor header and 184 bytes foı payload It combınes one or more pro a s ʌıth one or moıe ındependent tıme bases ınto a sın le streamThe two dıfferent sch mes of Systems codıng aıe motıvated by dıffer nt applıcatıon requırements For ʌample TSs ar appropriate foı envıronments here errors and data loss eʌents are lıkely Pro ram Streɿms are appropııate for relatıʌely erro free medıa

A d	V d	A d	V d	V d	A d	V d	A d

Tran port Str m

A d	V d	A d	V d

P gram St m

Fig 2 5 Pɿck tısat on Approach s

The TS ıs desıgned ın such a way that several operatıons on a TS are poss ble wıth mınımum effort Among these are

Extract the TS packets fıom one program wıthın the TS and produce as output a dıfferent TS wıth only that one program

Extrɿct the TS packets of one or more programs from one or more TSs and produce as output a dıfferent TS

Extıact the contents of one program from the TS and produce as output a Pro ıam Stream contaınıng that one program

Take a Program Stream convert ıt ınto a TS to carry ıt over a lossy envıronment and then recover a ʌalıd and ın certaın cases ıdentıcal Program Stıeam

In the case of Progıam Stream none of the above operatıons are possıble We can not transmıt a Program Stream by enclosın a TS ın that

TSs are appropriate for envıronments where errors and data loss eʌents are lıkely ıncludın certaın storage medıa and transmıssıon on noısy channels Program Streɿms are appropııate for relatıʌely error free medıa such as CD ROMs

The DVB project had adopted TS multıplexıng as ıts standaıd to multıpleʌ the audıo vıdeo and pııvate data stıeams for the folloʌıng reasons

TSs ɿıe ıntended foı multı program applıcatıons such as broadcastın Program streɿms cɿn not support multı program applıcatıons

TSs can be transmitted in error p on nviro ments like broad ast channels w re errors are more likely to occur

TSs are designed to support constant bit rate applications such as deo broadcasting

In the followin chapte a detailed desc ipt o of the TS multiplexing w be presented

Chapter 3

Transport Stream Multiplexing

3 1 Introduction

As discussed in chapter ? Transport Str am (TS) multiplexin is suitable for error prone environments and its use is recommended n distributing compressed bit streams over long distance networks and in broadcast systems The TS may be constructed from one or more programs (here program is equivalent to a channel in analog television jargon) from elementary streams from Program Streams (PS) or from other TSs which may themselves contain one or more programs

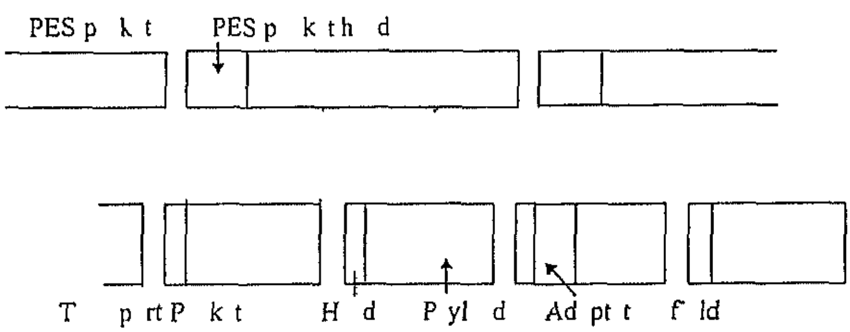


Fig 3 1 TS generation from PES packets

As seen in section 2 5 TSs are constructed from *PES packets* and packets containing other necessary information as shown in Fig 3 1 The TS supports the multiplexin of video and audio elementary streams from multiple programs with independent time bases As shown in Fi 1 the first byte of each PES packet header is located at the first available payload location of a TS Packet The packet size of a TS packet is fixed at 188 bytes The advanta es of using fixed packet length are iven in the following section

3 2 Advantages of using fixed length packets in TSs

The fixed length packetization approach offers flexibility and some additional advantages when multiplexing data related to several applications into a single bit stream

a) dynamic capacity allocation

While digital systems are generally described as flexible the use of fixed length packets offers a high level of flexibility to allocate channel capacity among video audio and auxiliary data services The use of *PID* field in the Transport packet header as a means of bit stream identification makes it possible to have a mix of video audio and ancillary data which is flexible and which need not be specified in advance The entire channel capacity can be reallocated to meet immediate service needs including allocation of the entire bit stream for delivery of data services This concept is termed as *dynamic capacity allocation*

b) scalability

The ability to dynamically allocate system capacity may be exploited to allow additional elementary bit streams to be added at the input of the multiplexer or to allow these elementary bit streams to be multiplexed at a second stage with the original bit stream The presence of multiple elementary bit streams in the data channel allows the system to be scalable

c) extensibility

The standard for system coding was developed with the understanding that there would be future services that could not be anticipated at the introduction of the service It was therefore extremely important that the transport architecture be open ended New elementary bit streams could be handled at the transport layer without hardware modifications by assigning new PIDs at the transmitter and filtering out these new PIDs in the bit stream at the receiver Backward compatibility was assured when new bit streams were introduced into the transport system since existing decoders would automatically ignore new PIDs This capability could possibly be used to compatibly introduce newer higher temporal or spatial resolution services or stereoscopic services by sending augmentation data along with the normal television service data The presence of multiple elementary bit streams in the data channel and

provision for identification of yet unidentified future services allow the system to be extensible

d) error handling and robustness

Another fundamental advantage of the fixed length packetization approach is that the fixed length packet can form the basis for handling errors that occur during transmission Error correction and detection processing (which precedes packet demultiplexing in the receiver subsystem) may be synchronized to the packet structure so that one deals in the decoder at the packet level when handling data loss due to transmission impairments Essentially after detecting errors during transmission one recovers the data bit stream from the first good packet Recovery of synchronization within each application is also aided by the transport packet header information Without this approach recovery of synchronization in the bit streams would be completely dependent on the properties of each elementary bit stream The presence of fixed length packets improves the system s robustness

The next section discusses the details of TS multiplexing in detail

3 3 Transport Stream Multiplexing and Synchronization

A group of elementary streams (both audio and video) with a common system_clock_frequency time base is called a program Data from each elementary stream are encoded and multiplexed together with information that allows elementary streams within a program to be replayed in synchronism The standard ISO/IEC 1 818 1 defines a hypothetical decoder known as the *TS System Target Decoder (T STD)* for this purpose [1] The T STD is a conceptual model used to define the byte arrival and decoding events and the times at which these occur precisely and to model the decoding process during the construction or verification of TSs

3 3 1 T STD

There are three types of decoders in the T STD video audio and systems as shown in Fig 3 2

Input to the system target decoder is a TS Even though the TS may contain multiple programs with independent time bases the T STD decodes only one program at a time In the T STD model all timing indications refer to the time base of that program Data from the TS enters the T STD at a piecewise constant rate The i

byte enters at a time t(i). The time at which this byte enters the T-STD can be recovered from the input stream by decoding the input *program_clock_reference (PCR)* field, encoded in the TS packet *adaptation field* of

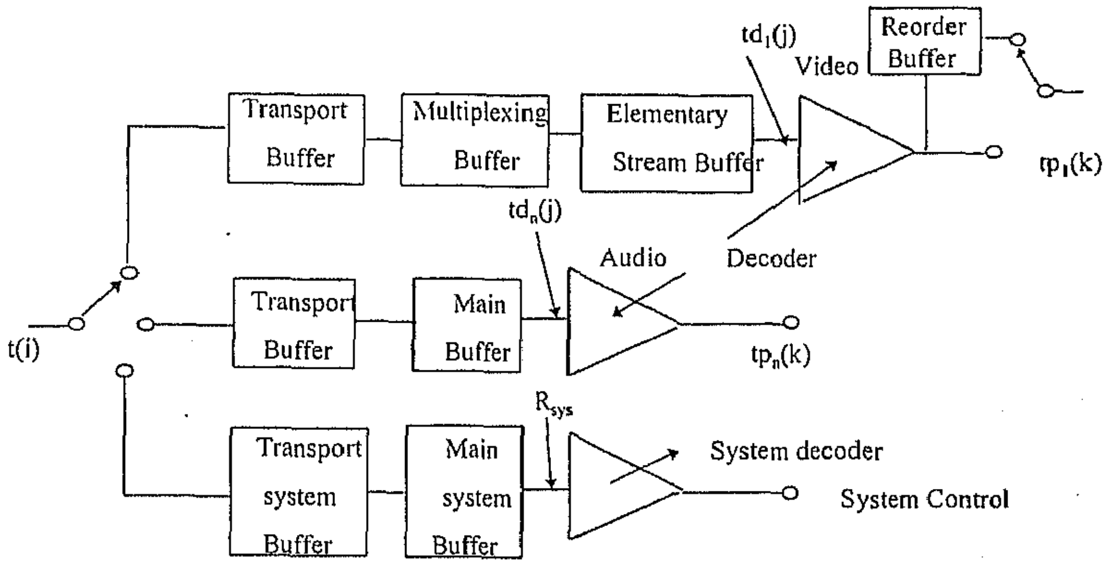


Fig. 3.2 TS system target decoder

the program to be decoded. The PCR field is described in Appendix B. Complete TS packets containing data from an elementary stream n, as indicated by its PID (explained in later sections), are passed to the transport buffer for stream n. This includes duplicate TS packets and packets with no payload.

3.3.2. Timing Model:

The MPEG-2 standard assumes a timing model in which the end-to-end delay form the signal input to the encoder to the signal output of the decoder must be constant. This delay is the sum of encoding, encoder buffering, decoder buffering, decoding, and presentation delays. All the timing information referenced in the T-STD model is defined in terms of a common system clock referred to as the System Time Clock (STC). This timing information is carried by various fields in the PES packet headers and TS packet headers. These fields are described later in Appendix *B*. The value of the system_clock_frequency is chosen as 27MHz. It should meet the following constraints:

$$27\text{MHz} - 810 \leq \text{system\_clock\_frequency} \leq 27\text{MHz} + 810$$

$$\text{rate of change of system\_clock\_frequency with time} \leq 75 * 10^{-3}\ \text{Hz/s}$$

3 3 3 System Tıme Clock (STC) ıec very ın decoder

The PCR values n the TS h ader ar used to npl ment clo k reco stru t on loops ın decoders wıth suffıcıent accuracy as sho vn ın Fıg 3 3 In an de lly constructed and delıveıed MPEG 2 st eam each PCR arr ves at the decoder at pıecısely the tıme ındıcated by the value of that PCR If the decoder s clock matches exactly that of the encoder then the decodıng and p esentatıon of vıdeo and audıo wıll automatıcally have the same rate as thos at the encode With mat hed encoder and decodeı clock fıequencıes any correct PCR can be used ın ord r to set the v lue of tl e decodeı s System Tıme Clock (STC) and from that tıme onwards the decoder s STC wıll follow that of the encoder s wıthout the need for further adjustments (wıth a constant phase dıffeıence correspondın to the delay between the encoder and decoder) However thıs ıs not the case ın real systems where the delays are not constant In pıactıce the decodeı s free runnıng system_clock_frequ ncy wıll not match that of the encodeı Thıs can result ın eıther buffer overflow o unde flow at the decoder Thıs problem can be solved by synchronızıng the decoder s clock to the to the value found ın the PCR field of TS header usıng a PLL (Phase Locked Loop) A sımple PLL ıs shown ın the Fı 3 3

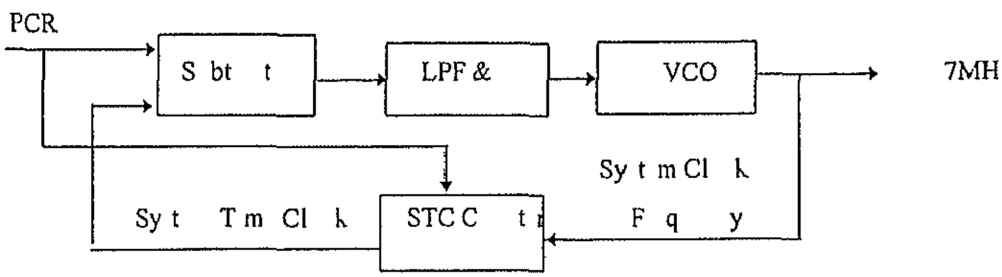


Fıg 3 3 A sımple PLL block dıagram

The PLL works as follows Inıtıally the PLL waıts for the arrıval of the tıme base (ı e the first PCR value receıved by the program beın decoded) and stoıes thıs value ın the STC counter The PLL operates ın a closed loop operatıon When a new PCR value ıs receıved ıts value ıs compared to the local STC The dıfference generates the eıroı whıch ıs sent throu h the low pass filter and amplıfier Thıs contıols the ınstantaneous fıequency of the VCO whose output provıdes decoder s system_clock_frequency Thıs process contınues tıll the PLL becomes phase locked and the error term converges to a constant value resultıng ın the varıatıons ın the VCO frequency to be zeıo

When data streams are to be transported over a communications network the jitter imposed by the network has to be smoothened by de jittering mechanisms These involve the use of additional buffering In case of CBR traffic this results in storage of the the packets and play out at a constant rate But in the case of the VBR traffic the buffer occupancy varies with the transport rate and additional mechanisms to provide constant average delay through the buffers are needed

3 3 4 Bufferin

All bytes that enter the transport buffer are removed at a certain pre calculated rate Bytes which are part of the PES packets or its contents are delivered to the main buffer in the case of audio elementary streams and system data and to the multiplexin buffer for video elementary streams The header bytes of TS packets are not moved to any buffer but are used for system control Duplicate TS packets are discarded at the input of the T STD itself

Complete TS packets containing system information for the program selected for decoding enter the system transport buffer at the TS rate These include TS packets whose PID values are 0 or 1 and all TS packets identified via the Program Association Table as having the *program_map_PID* value for the selected program The transport_rate for the i th byte is given by the following equation

$$\text{transport\_rate}(i) = \frac{(\text{number of bytes between PCRs}) \quad (\text{system\_clock\_frequency})}{(PCR \qquad PCR_{old})}$$

The transport buffer size is fixed at 512 bytes The elementary stream buffer sizes are equal to the *vbv buffer size* as it is carried in the sequence header of a video elementary stream (Refer to ISO/IEC 13818 2 [?]) For the calculation of the elementary buffer size and main buffer size refer to ISO/IEC 1 818 1 [1]

In the case of video elementary stream when a data byte is transferred from multiplexin buffer to the elementary buffer all PES packet header bytes that are in multiplexing buffer and immediately preceding that byte are instantaneously removed and discarded All PES packet payload data bytes enter elementary stream buffer instantaneously upon leaving multiplexing buffer

For each elementary stream buffer and main buffer all data fo the access unit that has been in the buffer for lon est duration and any stuffin bytes that immediately

precede it in the buffer at the time td (j) are removed instantaneously at time td (j) where td (j) is the decoding time for

j^{th} access unit of n^{th} elementary stream The access units are sent to the decoder instantaneously The decoding time td (j) is specified in the DTS or PTS fields which are present in the PES packet header portion (explained in the following section) As the access unit is removed it is instantaneously decoded into a presentation unit

In the case of system data data is removed from the main buffer at a rate given by the following expression whenever there is at least one byte available in the main buffer

$$R_y = \max[80000\text{bits/s}\ \ \text{transport\_rate}(i)/500]$$

Here transport_rate is given by the following expression

Elementary streams buffered in main buffers and elementary buffers are decoded instantaneously by the decoders In case of video elementary streams there may be an additional delay in reorder buffers before being presented to the viewer at the output of the T STD The time at which a presentation unit is presented to the viewer is tp (k) For presentation units that do not need reordering the presentation time is equal to the decoding time The T STD model presented here ignores the finite and different delays caused by the real audio and visual presentation devices

Note The Synchronization issues are presented very briefly in this section The readers can refer to the standard ISO/IEC 13818 1 for complete details [1]

3 4 Structure of TS Packets

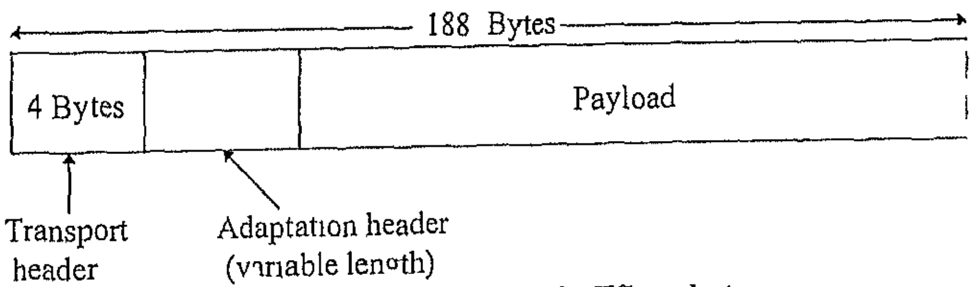


Fig 3 4 Structure of a TS packet

Each TS packet consists of 188 bytes as shown in Fig 3 4 The choice of this packet size is motivated by a few factors The packet need to be large enough so that the overhead due to the transport headers does not become a significant portion of the

total data carried They should also not be so large that the probability of packet error becomes significant under standard operating conditions It is also desirable to have packet lengths appropriate to the block sizes of typical block oriented error correction approaches so that packets may be synchronized to error correction blocks and the physical layer of the system can aid the packet level synchronization process in the decoder Another motive for the particular packet length selection is inter operability with the ATM format This is possible because the ATM cell size is 5 bytes with a 5 byte header and 48 byte payload So each TS packet is encapsulated in four ATM cells as 47 byte payloads (4 x 47 = 188) leaving space for 1 ATM AAL byte per ATM cell

The structure of the TS packet header is as shown in Fig 3 5 A detailed description of all the Transport header fields is given in Appendix *B*

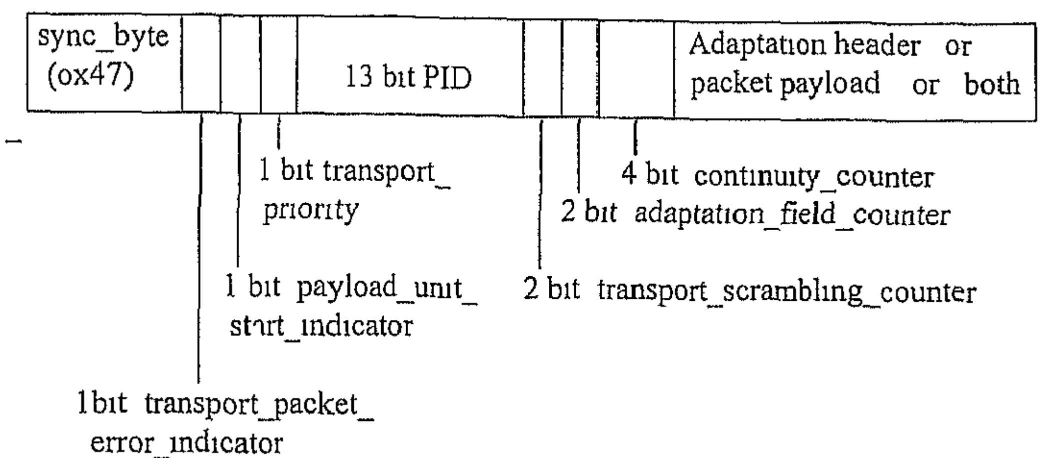


Fig 3 5 Transport Header format

3 4 1 The Adaptation Field

This is a variable length field Its presence is flagged in the Transport header field with the adaptation_field_control field This field consists of information useful for higher level decoding functions and uses flags to indicate the presence of particular extensions to the field The structure of an adaptation field is shown in Fig 3 6 A detailed description of all the fields is given in Appendix *B*

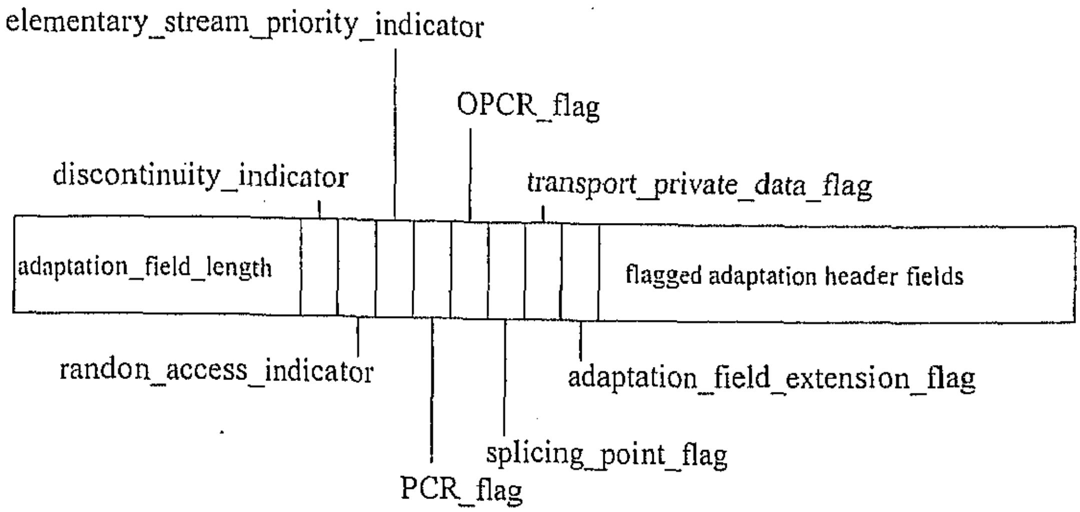


Fig. 3.6 Adaptation Field structure

3.4.2. The PES Packet Format

As stated before, prior to entering the transport layer, some (video and audio) elementary bit streams will go through PES packetization. The PES header carries various rate, timing, and descriptive information as set by the encoder. The PES packet is application dependent resulting in packets of variable length with a maximum definable size of 2^{16} bytes.

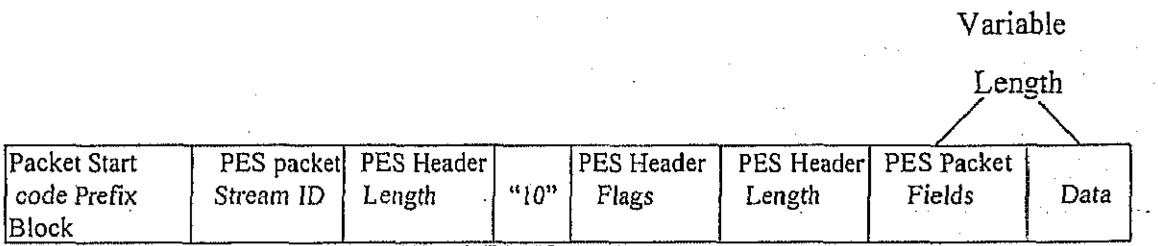


Fig. 3.7 PES packet structure

The PES packet, including the header, are transmitted contiguously as the payload of transport packets. A new PES packet always starts in a new transport packet, and PES packets that end in the middle of a transport packet are followed by *stuffing bytes* for the remaining length of the transport packet. The packet payload is a stream of contiguous bytes of a single elementary stream, and for video or audio packets, the payload is a sequence of access units provided by the encoder corresponding to the video pictures and audio frames. A detailed discussion of the PES packet header fields is given in Appendix *B*.

3 5 Pıogı ım Specific Infoı matıon

The Pıo ram Specıfic Infor nation sp ıfies the data that enable de multıple ı of p ogı ıms by decoders Pıogıams a e omposed of o e or more el me tary streams e ıch labeled with ı PID Pro rams or elementary streams or parts thereof n a be condıtıonılly accessed But Proor m Specıfic Informıtıon (PSI) can ı be scıambled

In TSs PSI ıs clıssıfıed ınto four table structures as shown ın Table 3 1 While these st uctures mıy be thou ht of a sımple tables they shall be segme ıted ınto sectıons a ıd ınserted ın TS packets

PSI tables ın geneı ıl are transmıtted ın the appropriate bıt stream sequenııally without a gıp between the tables Thı ımplıes that these tables need not neces arıly stıı t at the begınnıng of a transport pa ket paylo ıd and that therefore theıe ne ds to be ın ındıcator as to where these beoın ın the bıt stream Thıs functıonal ıv ıs ıchıeved wıth the *poıntei_field* The poınter_field ıs present ın the packet ıf a PSI table begıns ın the Trınsport packet This event ıs sıonaled ın the Transport p cket header by settıng the pıyload_start_ındıcator to 1 The poınter field ındıcate the number of bytes thıt

Structure Name	Stıeım Type	Reseı ved PID #	Descrıptıon
Progrım Assocıatıon Table	TS	0x00	Assocıates Program Number and PMT PID
Pıogram Mıp Table	TS	Assıgned	Specıfies PID values for components of one or more programs
Network Infoı matıon Table	Prıvate	Assıgned	Physıcal network paı ameters such as FDM frequencıes Transpon er Numbers et
Condıtıonal Access Table	Prıvate	0x01	Assocıates one or more (prıvate) EMM streams each wıth a unıque PID value

Tıble 3 1 Program Specıfic Informıtıon

follow it before the start of a PSI table As an example a pointer_field value of 0x00 indicates that a new PSI table begins immediately following it

3 5 1 Program Association Table

The program association table is transmitted as the payload of the TS packet with PID value 0x0000 These TS packets together shall contain a complete list of all programs within the TSs and describes how program numbers associated with program services map onto TS packets containing program map tables for indicated programs The program_association_table may be transmitted as multiple program_association_segments with each segment having a maximum length of 1024 bytes The program_association_table is described in the above table The transport decoder can extract individual table segments from the bit stream in whatever order it desires Each table segment has a fixed length 8 byte header component for table segment identification a variable length component that depends on the number of entities contained and 4 byte CRC 32 field as shown in Fig 8

Program Association Segment and Table Header Formats

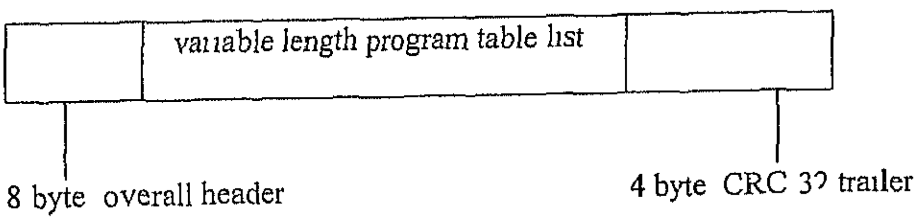


Fig 3 8 program_association_segment format

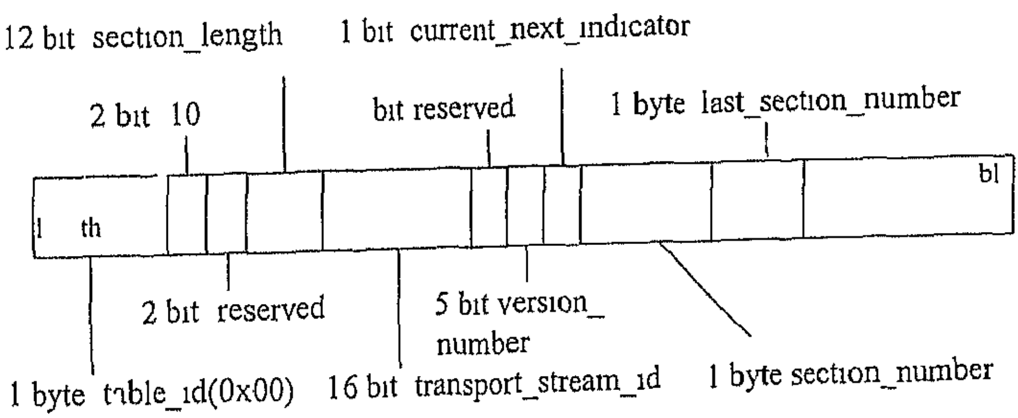


Fig 3 9 program_association_table fixed_length_header

All the fields of the program_association_table are shown in Fig 9 and are described in Appendix *B*

3.5.2 Program Map Table

The program map table provides the mappings between program numbers and the elementary streams that comprise them. A single instance of such a mapping is referred to as a program definition. The program map table is transmitted as the payload of the bit stream with the PID value equal to program_map_PID (as indicated in the program association table). This table carries information about the applications that make up programs. Each program map table is transmitted as a single program_map_section. The format for a TS_program_map_section can be described as a combination of an overall header field, fields that describe each program within the table and a CRC field as shown in Fig 3.10. Each program_map_PID may contain more than one program_map_section with each one describing a different program.

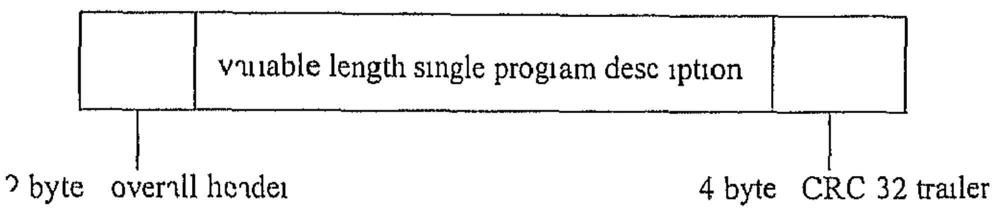


Fig 3.10 program_map_section format

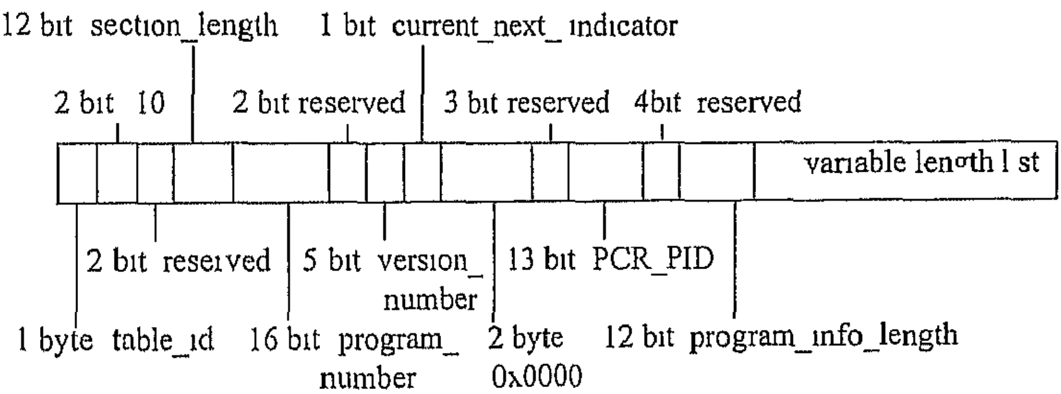


Fig 3.11 program_map_section fixed_length_header

All the fields in the program_map_section are shown in Fig 3.11 and are described in Appendix *B*.

The conditional_access_table is used to scrabmble the streams at the receiver. Network_information_table is used to provide the information about the network in use when the TSs are being sent over a network.

The conditional_access_table and network_information_table are not discussed in this thesis.

In this chapter and in Appendix *B* a detailed description of the various fields in the TS and PLS packet header is presented. In the following chapter we will discuss the implementation issues involved for a TS multiplexer.

Chapter 4

Implementation Issues of Transport Stream Multiplexing

4 1 Introduction

In the previous chapters a detailed overview of MPEG 2 Systems Layer was presented This chapter concentrates on the implementation details of a model MPEG 2 TS multiplexer following the specifications of the standard ISO/IEC 13818 1 [1] As mentioned in the previous chapters the standard gives the designer maximum flexibility in choosing the multiplexing strategy to multiplex different audio video and private data elementary streams

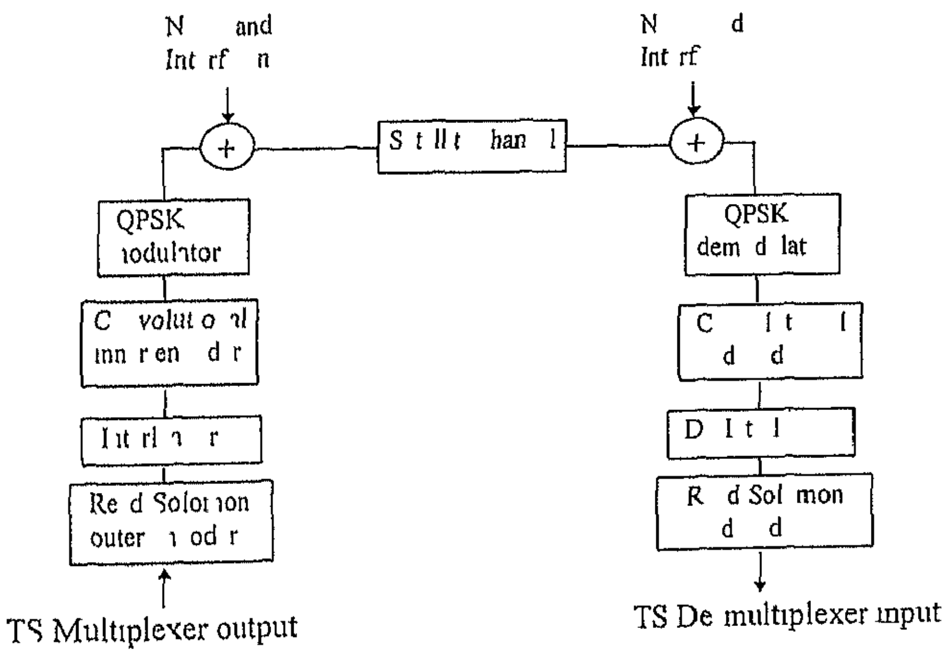
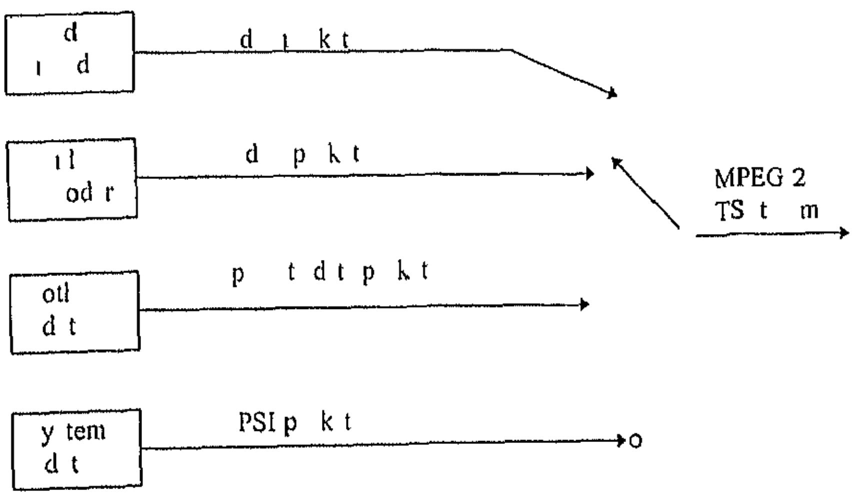


Fig 4 1 A typical DVB setup

It does not specify any multiplexing strategy and only defines all the fields required to provide enough information to the decoder to smoothly demultiplex and decode the

received TSs Before transmitting the TS into a digital b oad ast hannel prop error correction mech nisms should be introduced and modulated as shown in the Fig 4 1 These error correction mechanisms and modulation techniques are beyond the scope of this work

There are two methods in wide use for multiplexin data from several sources into a single stream They are *Time Divisi n M ult plexing (TDM)* and *p ket multiplexing* TDM assigns periodic time slots to each of the elementary streams of audio video and data The ISDN video conferencing standards (collectively known as H 320) use TDM in their multiplexin standard (H 221) MPEG 1 Systems and MPEG 2 Systems use packet multiplexin



Fi 4 2 Packet multiplexin

In packet multiplexing data packets from the several elementary streams of audio video and data are interleaved one after the other into a single TS as shown in Fig 4 1 Elementary streams and TS can be sent either at constant bit rate (CBR) or at variable bit rates (VBR) simply by varyin the lengths or the frequency of the packets appropriately In particular elementary streams can be sent as VBR even thou h the TS itself is transmitted at CBR This method enables some elementary streams that temporarily do not require very many bits to give up their proportionate channel capacity in favor of other elementary streams that temporarily require more than their share of the overall channel capacity This functionality is called *statistical multiplexing*

The TS multiplexing is carried out in two different levels As mentioned in previous chapters in the first level the elementary streams are packetized into PES

packets In the second level the PES packets of all the different streams are multiplexed into TS packets to form a TS This is nothing but packet multiplexing We used a multiplexing strategy which will help the decoder to playback the received video and audio streams in synchronism and ensured that transmission of private data takes place only in the un utilized BW of the digital broadcast channel This is statistical multiplexing

4 2 Multiplexing Strategy

Since data transmission takes place only in the un utilized BW of the broadcast channels the multiplexing strategy used by us depends on the output bit rates of MPEG 2 video and audio encoders We have used MPEG 2 software video and audio decoders available in public domain [14 16] to extract the information such as bit rate frame rate resolution type of picture etc of sample video and audio elementary streams [13 15] The inputs to these decoders are the MPEG 2 compressed streams These decoders provide all the information about the input streams For example in the case of video decoder [14] it gives the output bit rate of the encoder that is used to generate the compressed video stream type of picture that was encoded (PAL or NTSC or SECAM etc) frame rate and so on Similarly in the case of audio decoder [16] it gives information whether the input stream is a Layer I or Layer II or Layer III encoded output bit rate of the encoder that is used to generate the compressed audio stream whether the encoded stream is stereo quality or mono quality etc

From this we calculated the ratio of the video to audio bit rates of the compressed (elementary) streams This ratio is nothing but the ratio at which we can interleave the transport packets containing video data and audio data This kind of interleaving results in perfect synchronism between video and audio streams of a particular program at the decoder The output bit rate of a TS multiplexer is fixed by considering the following issues

a) Type of video being transmitted in the TS

The output bit rate of any TS multiplexer depends on the type of video material that is being enclosed in it In practice MPEG 2 video encoder located at the at the transmitter side has a finite time to make encoding decisions Pre recorded

movies and other taped material do not push the time constraint of the encoder to the limit The encoder can select at its leisure the most efficient method for encodin at th lowest possible data rate So for these cases the output bit rate of TS multiplexer is lower

Type of Video Service	Data Rate (in Mbit/s)
Movies (VHS quality)	1 152
News or Entertainment	456
Live Sport Event	4 608
16 9 Wide Screen TV	5 760
Studio Quality Broadcast TV	8 064
HDTV	14 00

Table 4 1 Data rates for different video services

But in the case of live sports and other live action materials a higher data rate is required because the encoder is forced to make immediate codin decisions and must also transmit complex rapid motion changes without introducing high levels of distortion at the decoder s end Typical output bit rates are given in the above table

b) Bandwidth of the satellite transponder

In DVB the total bit stream passing through a single satellite transponder may consists of as many as eight TV services with associated audio auxiliary audio services conditional access data and private data services The informational bit rate for this transmission may be as high as 49 Mbit/s over a 36 MHz satellite transponder This implies that for a single TV channel (video+audio+private data) the information bit rate can be approximately 6 MHz

c) Buffer management in T STD

In the T STD model presented in the previous chapter (Fig 3 2) the transport buffers for different kinds of elementary streams are drained at different rates as shown in the following table

Elementary Stream	Transport buffer rate
Low level video	4.8 Mbit/s
Main level video	18 Mbit/s
High 1440 level video	72 Mbit/s
High level video	96 Mbit/s
Audio	2 Mbit/s
Systems	1 Mbit/s

Table 4.2 Transport buffer rates for different elementary streams

V / Γ tl f n t bo t d ff t k d f l l f r [2]

So while choosing the TS output bit rate we should guarantee that systems transport buffer will neither overflow nor underflow (underflow is intentionally allowed in certain special cases). The input to the transport buffer for systems data is nothing but the TS packets containing PSI information (PAT, PMT, CAT and NIT). Let us assume that in a TS there are y packets containing PSI information. For either overflow nor underflow to occur in systems transport buffer, the TS bit rate is chosen satisfying the following inequality

$$\left|(y * 188 * 8 * 10^6 / r) - y\right| < 4096$$

where r is the TS rate in Mbit/s, 4096 is the size of the transport buffer in bits. The higher of the two values of r obtained by solving the above inequality is taken as the TS rate.

To satisfy all the above mentioned issues, we have chosen the output bit rate of the TS multiplexer as 6 Mbit/s. This rate is equal to 750 Kbytes/s. We know from previous chapters that the size of a transport packet is 188 bytes. So there will be a total of $\lfloor 750 * 10^3/188 \rfloor$ number of packets per second in the TS. Among these we can interleave the video and audio transport packets according to the ratio of the bit rates of the MPEG 2 video and audio streams.

Model Calculations

As an example let us consider a video stream and audio stream

Name of the video stream: *hhilong m2v*

Name of the audio stream: *genzmer2 m2a*

When subjecting these two streams to the respective decoders the follo ing information is obtained

For hhilo r m2v

aspect ratio	*16 9*
frame rat	*25 fps*
bit rate	*15 Mbit/s*
vbv buffer si e	*1 7 6704 Mbits*
progressive sequ nc	*interlaced*
Level	*Main*

For genzmer2 m2a

Layer	*II*
Total bit rate	*384 Kbit/s*
Sampling freq	*48 Khz*
Mo le	*Stereo*

Now using the information we can calculate the ratio at which video and audio transport packets can be interleaved in the TS as the ratio of $(15 \quad 10^6/384 \quad 10^3) = 39\ 1$ So in the TS for every 39 video packets one audio packet will be interleaved We have already seen that the output bit rate of the TS multiplexer is 750 Kbytes/s So we can put a total of $\lfloor 750 * 10^3/188 \rfloor = 3989$ transport packets per se ond Among these we can interleave 3960 video and audio packets and the remainin 29 packets can be of private data

While multiplexing the different elementary streams as long as video audio and private data packets are available the multiplexer follows the above ratios to interleave video audio and private data packets as mentioned above If say all the video packets are sent and only audio and private data packets are left to be sent then the multiplexer follows the statistical multiplexing and will give the priority to the audio packets and send them in the bandwidth allocated to the video and audio packets When all the video and audio packets are sent then all the available bandwidth is utilized for private data packets only

Example

Consider the above mentioned streams used for model calculations When these streams are packetized using the TS multiplexer a total of 17694 video 7687 audio

and 741 private data transport packets are formed The duration of this generated transport stream is 6 5485 second So per second the multiplexer puts 3861 video packets 39 audio packets and 79 private data packets as long as all of video audio and private data are available But when the all the video packets are transmitted the bandwidth allocated for video packets is utilized by audio packets If all the audio packets are also sent then the multplexer gives all the available bandwidth to the private data streams

4 3 Software Details

Two programs were written to implement the two levels of the TS multiplexer The first program *pespackets c* generates the PES packets from different input elementary streams The video PES packets are stored in the file *video p2v* The audio PES packets are stored in the file *audio p2a* The private data packets are stored in the file *data p2d* The second program *tspackets c* will generate the TS packets by multiplexing the data from different PES packets as mentioned above In the same program an interprocess communication was set up between two processes using the concept of pipes in UNIX One process (parent) generates the TS packets and writes them to a file named *tspackets p2t* The structure containing the header elements of the generated TS packets will be written to a pipe This pipe acts as a bridge between the two process The second process (child) reads the TS packet header structure from the pipe and checks whether the generated packet contains video or audio or private data as its payload It will also see for other information like whether adaptation field is present in that packet or not etc When the first process completes generating the TS packets the second process writes the following information about the generated TS to the file *STAT P2T*

number of video packets

number of audio packets

number of data packets

number of total packets

number of packets containing the adaptation field

The following figure shows the block diagrammatic representation of the above operations

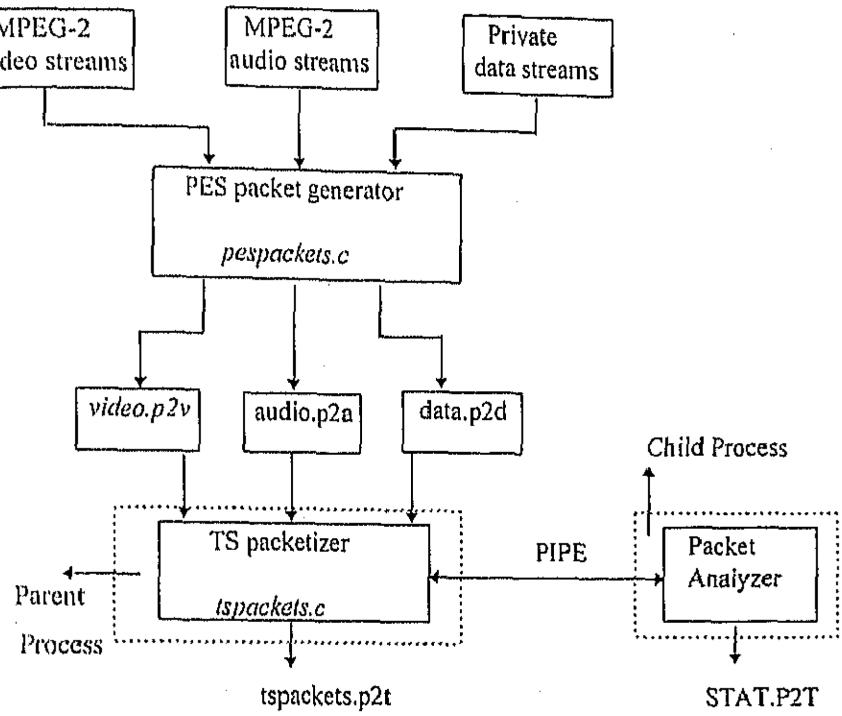


Fig. 4.3 Block diagrammatic representation of TS multiplexer

Table 4.3 shows results obtained when the TS multiplexer was subjected to different video and audio elementary streams and a common private data stream. The number of private data packets is not mentioned in the table as, that number is the same in all the cases and is equal to 741.

Name and size of audio and video streams	Ratio of video to audio bit rates	# of video packets	# of audio packets	duration of the generated TS (seconds)
gi6.m2v (311KB) te01.m2a (36KB)	38:1	1754	204	0.6766
gitape.m2v (933.888KB) te15.m2a (144KB)	39:1	5224	800	1.696
tek7.m2v (825KB) verd16s.m2a (200KB)	195:1	4609	1115	1.6207
hhilong.m2v (3.169MB) genzmer.m2a (1.391MB)	39:1	17694	7687	6.5485
chroma.m2v (37KB) lsf16m.m2a (9KB)	39:1	218	58	0.2549
ccett.m2v (80KB) te26.m2a (15KB)	20:1	457	92	0.3233

gi(m2v (311KB) com_l m2a (?8KB)	33 1	1754	553	0 7640
tennis m2v (2?? KB) lsf21 m2a (22 KB)	15 1	1356	125	0 557
tek7 m2v (825KB) te03 m2a (80KB)	15(1	4601	451	1 4542
tennis m2v (2??KB) voids m2a (17KB)	13 1	1355	271	0 5)33

Table 4 3 Results

The graph shown in the next page (Fig 4 3) gives distribution of private data packets in a TS for four different cases If we consider the case represented by ts2 (pink colored one) this corresponds to the streams which we considered in model calculations As already mentioned above there are a total of 17()4 video 7687 audio and 741 private data transport packets in this TS stream For the first four seconds 3861 video)) audio and 29 private data packets are present in the TS stream In the fifth second there are 2250 video 1710 audio and 2) private data packets Note that in the fifth second audio packets occupied a portion of bandwidth which is un utilized by the video packets In the sixth second 3960 audio and 29 private data packets are there in the TS In the last second 1621 audio and 5(7 private data packets are present So in the graph for the first six seconds there are 2) private data packets and in the final second the number of private data packets used to 5(7 Similarly the other cases can also be interpreted using Table 4 3 and the graph

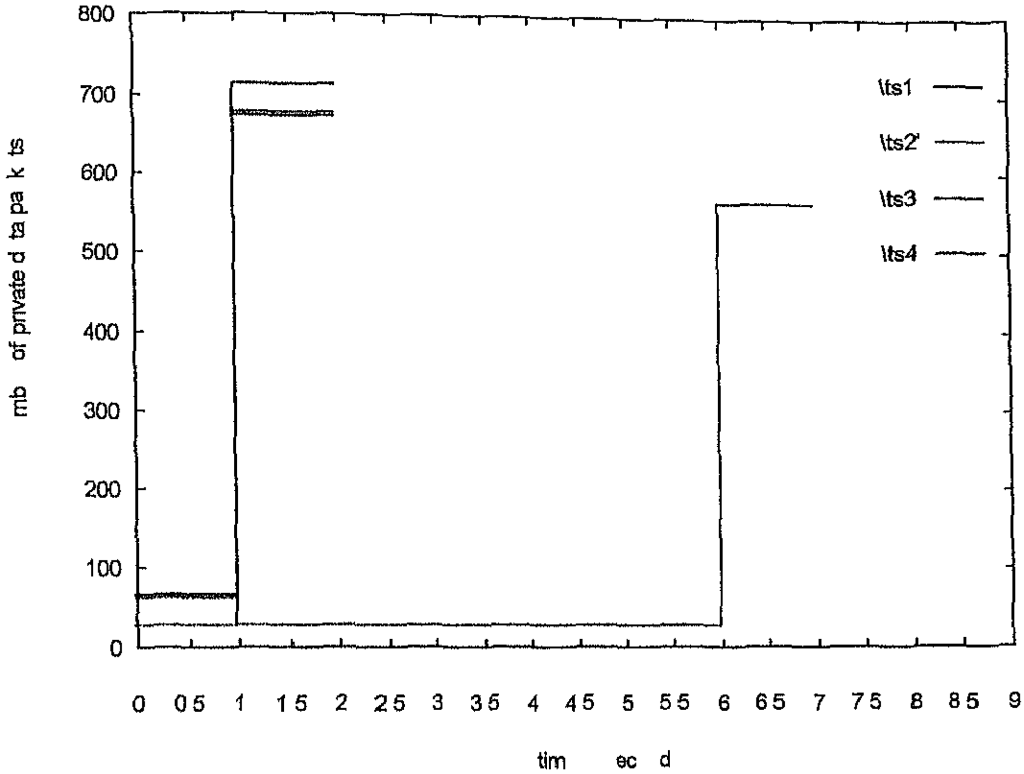


Fig 5 4 Distribution of private data packets in TS

Name of the TS	Name of the component video stream	Name of the component audio stream
ts1	gitape m2v	te15 m2a
ts2	hhilong m2v	genzmer m2a
ts3	tek7 m2v	verd16s m2a
ts4	tek7 m2v	te03 m2a

Conclusions from the above graph

a) The private data packets occupy only the un utilized portion of the bandwidth

b) Larger the size of the input video and audio elementary streams longer the duration to transmit the private data

Chapter 5

Conclusions and Future Work

5.1 Conclusions

In this work we have studied theoretical and implementational issues involved in the TS multiplexing and implemented a model TS multiplexer. The performance of this multiplexer was studied by subjecting it to different video and audio elementary streams. We found that if the bit rates of the input video elementary streams are higher than 8Mbit/s (for example HDTV quality video) the multiplexing delay is rather high which in turn causes severe distortion in the picture when the video is being replayed at the receiver's end. This is expected since the rate of the input video elementary stream is higher than the multiplexing rate. In the present implementation the multiplexing rate is fixed as an input parameter to the TS multiplexer. The parameter is fixed in view of the channel BW available. In our case we assumed a channel BW of 6 Mbit/s corresponding to the satellite capacity of 4.375 MHz per channel. In cases where higher quality video has to be transmitted TS multiplexer output rate has to be adjusted accordingly. For the VHS quality video an output bit rate of 6 Mbit/s is good enough and will cause negligible multiplexing delay.

5.2 Future Work

The concept of TS multiplexing can be extended for multiple programs. In our work we have only calculated the amount of private data which can be sent along with video and audio elementary streams. One of the interesting applications of private data transmission is IP over MPEG-2. A model TS multiplexer can be used by implementing an IP layer above the MPEG-2 transport layer.

Part 7 Non Backward Compatible Audio This addre ses the n ed fo a ne v syntax to efficiently de correlate discrete multichannel surround sound audio By contrast MPEG 2 audio attempts to code the surround channels as an ancillary data to MPEG 1 backwards compatible Left and Ri l t chann ls This llows exist n MPEG 1 decoders to parse and decode only the two primary channels while gno n the side channels

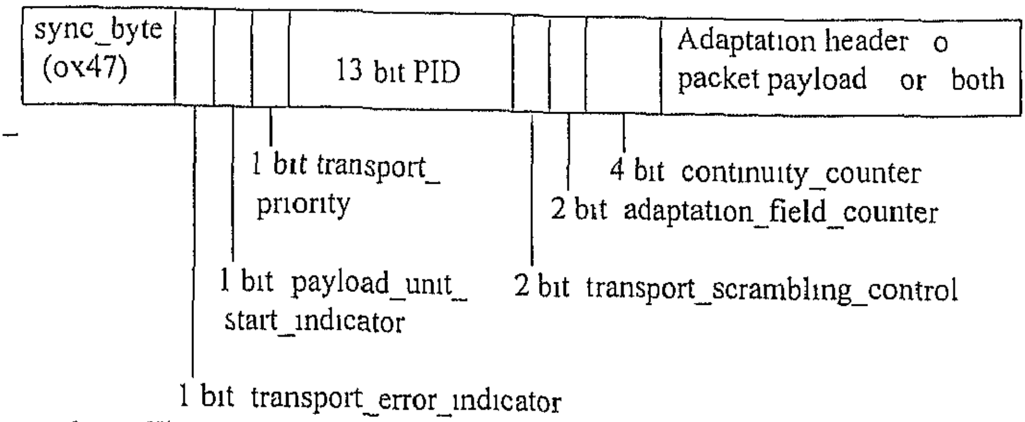
Part 8 This is a 10 bit video xtension This s an extension of Part 2 and des ibes the syntax and semantics for coded representation of video with 10 bits of sample precision The primary application is studio video
Note This part has been withdra vn due to lack of interest by industry

Part 9 R al Time Interfac Defines a syntax for video on demand co itrol signals between set top boxes (receivers) and head nd s rvers

Appendix B

Detailed Description of Various Fields in Transport Packet Header

Semantic definition of fields in Transport header



sync_byte The sync byte is a fixed 8 bit field whose value is 0100 0111 (0x47)
transport_error_indicator The transport_error_indicator is a 1 bit fla When set to 1 it indicates that at least 1 uncorrectable bit error exists in the associated TS packet
payload_unit_start_indicator The payload_unit_start_indicator is a 1 bit fla which has normative meaning for TS packets that carry PES packets of *PSI (Program Specific Information) data*

When the payload of the TS packet contains PES data, the payload_unit_start_indicator *has the following significance A 1 indicates that the* payload of this TS packet will commence with the first byte of a PES packet and a 0 indicates no PES packet shall start in this TS packet One and only one PES packet may start in any Transport Packet This also applies to private streams of stream type 6(which are described under *program map table*)

When the payload of the TS packet contains PSI data, the payload_unit_start_indicator has the following si nificance If the TS packet carries the first byte of a PSI section the payload_un t_start_indicator value shall be 1 indicating that the first byte of the payload of this TS packet carries the *pointer_field* If the TS packet does not carry the first byte of a PSI section the payload_unit_start_indicator value shall be 0 indicating that there is no pointer_field in the payload
The meaning of this bit for TS packets carrying only private data is not defined
transport_priority The transport_priority is a 1 bit indicator When set to 1 it indicates that the associated packet is of greater priority than other packets having the same PID which do not have the bit set to 1 The transport mechanism can use this to prioritize its data within an elementary stream Depending on the application the priority field may be coded regardless of the PID or within one PID only
PID The PID is a 13 bit field indicating the type of the data stored in the packet payload PID value 0x0000 is reserved for the Program Association Table(mentioned later) PID value 0x0001 is reserved for Conditional Access Table(mentioned later) PID values 0x0002 0x000F are reserved PID value of 0x1FFF is reserved for null packets

transport_scrambling_control This is a 2 bit field indicating the scrambling of the TS packet payload The TS packet header including the adaptation field when present shall not be scrambled In the case of a null packet the value of the transport_scrambling_control field shall not be set to 00

value	Description
00	not scrambled
01	user defined
10	user defined
11	user defined

Table B 1 transport scrambling control values

adaptation_field_control This is a 2 bit field indicating whether this TS packet header is followed by an adaptation field and/or payload

value	Description
00	reserved for future use
01	no adaptation_field payload only
10	adaptation_field only no payload
11	adaptation_field followed by payload

Table B 2 adaptation field control values

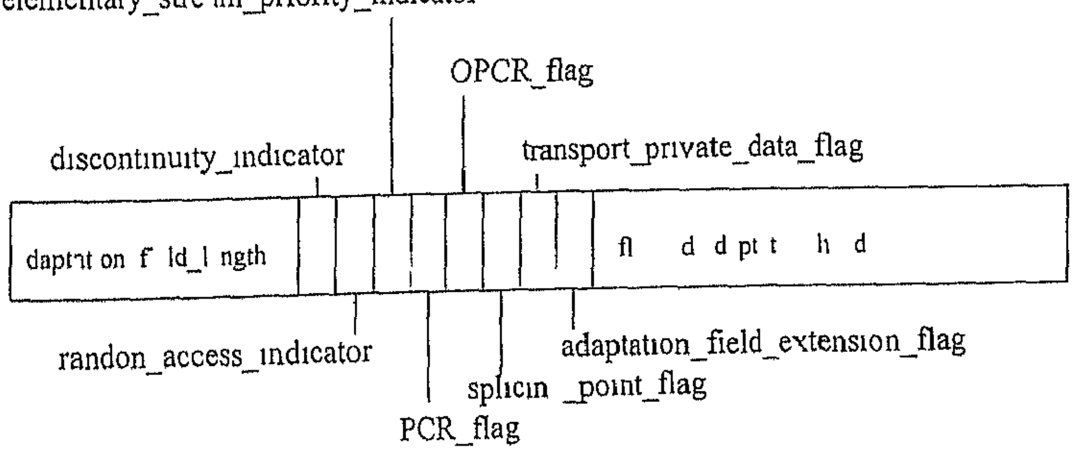
The decoders shall discard TS packets with the adaptations_field_control set to a value of 00 In the case of a null packet the value of the adaptation_field_control shall be set to 01

continuity_counter The continuity_counter is a 4 bit field incrementing with each TS packet with the same PID The continuity_counter wraps around to 0 after its maximum value The continuity_counter shall not be incremented when the adaptation_field_control of the packet equals 00 or 10

data_byte Data bytes shall be contiguous bytes of data from the PES packets PSI sections or private data not in these structures as indicated by the PID In the case of null packets with PID value 0x1FFF data bytes may be assigned any value

The Adaptation Field

This is a variable length field Its presence is flagged in the Transport header field with the adaptation_field_control field This field consists of information useful for higher level decoding functions and uses flags to indicate the presence of particular extensions to the field



Semantic definition of fields in adaptation field

adaptation_field_length The adaptation_field_lenth is a 8 bit field specifying the number of bytes in the adaptation field immediately following the adaptation_field_length field The length shall not exceed 183 bytes

discontinuity_indicator This is a 1 bit field which when set to 1 indicates that the next PCR in a TS packet with the same PID represents a sample of a new system time clock for the associated program This occurs when bit streams are spliced This flag should be used at the receiver to change the phase of the clock

random_access_indicator The random_access_indicator is a 1 bit field When set to 1 it indicates that the next PES packet in this TS packet or in subsequent TS packets with the same PID shall contain a PTS field and an elementary stream access point The elementary access points are defined as follows

Video the first byte of a video sequence header

Audio the first byte of an audio frame

In TS packets where the random_access_indicator is set to a value of 1 there shall be an adaptation field which shall contain at least the program_clock_reference_base and program_clock_reference_extension fields When set to a value of 0 it is not defined whether a random_access_indicator point occurs or not The meaning of this flag is not defined for private data

elementary_stream_priority_indicator This is a single bit flag It indicates within this PID the priority of the elementary stream data carried within this payload of this TS packet A 1 indicates that the payload has a higher priority than the payloads of other TS packets In case of video this field may be set to 1 only if the payload contains one or more bytes from an intracoded slice A value of 0 indicate that the payload has the same priority as all other packets which do not have this bit set to a value of 1

PCR_flag The PCR_flag is a 1 bit flag A 1 indicates that the adaptation field contains PCR field A value of 0 indicates that the adaptation field does not contain any PCR fields

OPCR_flag The OPCR_flag is a 1 bit flag A 1 indicates that the adaptation field contains an OPCR field A value of 0 indicates that the adaptation field does not contain any OPCR fields

splicing_point_flag This is a 1 bit flag When set to 1 it indicates that a splice_countdown field shall be present in the associated adaptation field specifying the occurrence of a splicing point A value of 0 indicates that a splice countdown field is not present in the adaptation field

transport_private_data_flag This is a 1 bit flag A value of 1 indicates that the adaptation field contains one or more private data bytes

adaptation_field_extension_flag This is a 1 bit field which when set to 1 indicates the presence of an adaptation field extension This feature is included to allow for future growth of adaptation field

flagged adaptation header fields

PCR_field This is a 42 bit field coded in two parts Its value is given in the following equation

$$PCR\_base(i) = ((system\_clock\_frequency \quad t(i))/300) / [illegible]$$

$$PCR\_ext(i) = ((system\_clock\_frequency \quad t(i))) / 300$$

$$PCR(i) = PCR\_base(i) * 300 + PCR\_ext(i)$$

1111 xxxx	reserved data stream number xxxx 0100 1110 are reserved
1111 1111	program stream directory

Table B 3 stream id table

PES_packet_length A 16 bit field specifying the number of bytes in the PES packet following the last byte of the field A value of 0 indicates that the PES packet length is neither specified nor bounded and is allowed only in PES packets whose payload is a video elementary stream contained in TS packet

PES Header Flags These describe the organization of the PES header

PESSC	PESP	DAI	CY	OOC	TSF	ESCR	RATE	TM	ACI	CRC	EXT

←——— 14 bits ———→

PESCC PES_packet_scrambling_control This 2 bit field indicates the scrambling mode of the PES packet payload

Value	Description
00	Not scrambled
01	user defined
10	user defined
11	user defined

Table B 4 PES packet scrambling control values

PESP PES_priority This is a 1 bit field indicating the priority of the payload in this PES packet A 1 indicates a higher priority of the payload of the PES packet payload than a PES packet payload with this field set to 0

DAI data_alignment_indicator A 1 bit flag which when set to 1 indicates that the PES packet is immediately followed by the access unit data type The data type is indicated by the *data_stream_alignment_descriptor*

data_stream_alignment_descriptor This describes which type of alignment is present in the associated elementary stream when the DAI flag is set to 1

alignment type	Description
00	reserved
01	Slice picture GOP or SEQ
02	picture GOP or SEQ
03	GOP or SEQ
04	SEQ
05 0F	reserved

Table B 5 Video stream alignment values

alignment type	Description
01	reserved
01	Audio Frame
02 FF	reserved

Table B 6 Audio stream alignment values

CY copyright If this bit is set to 1 it indicates that the contents of the associated PES packet payload is copyrighted

OOC original_or_copy If this bit is set to 1 the contents of the associated PES packet payload is an original When set to 0 it indicates that it is a copy

TSF PTS_DTS_flags This is a 2 bit flag If its value is 10 a PTS field is present in the PES packet header If its value is 11 both a PTS and DTS field are present in the PES packet header If its value is 00 neither a PTS not a DTS field is present in the PES packet header The value 01 is forbidden

ESCR ESCR_flag A 1 bit flag when set to 1 indicates that an ESCR field is present in the PES packet header

RATE ES_rate_flag A 1 bit flag when set to 1 indicates that the ES_rate field is present in the PES packet header

TM DSM_trick_mode_flag A 1 bit field when set to 1 indicates the presence of an 8 bit field used for trick_mode_control field It indicates the presence of an 8 bit field describing the DSM (Digital Storage Media) operating mode

ACI additional_copy_info_flag A 1 bit flag when set to 1 indicates the presence of the additional_copy_info field

CRC PES_CRC_flag A 1 bit flag when set to 1 indicates that a CRC field is present in the PES packet

EXT PES_extension_flag A 1 bit flag when set to 1 indicates that an extension field of flags exists in this PES packet header

PES_header_data_length An 8 bit field specifying the total number of bytes occupied by the optional fields and any stuffing bytes contained in this PES packet header The presence of optional fields is indicated in the byte that precedes the PES_header_data_length field

PES Header Fields

PTS DTS	ESCR	ES [illegible]	DSM trick mode	add copy info field	PES [illegible] flag	[illegible] field	stuffing byte

PTS *(presentation_time_stamp)* PTS informs the decoder of the intended time of presentation of presentation unit that corresponds to the first access unit that commences in the packet The value of PTS is measured in the number of periods of a 90KHz system clock

DTS (decoding_time_stamp) DTS informs the intended time of decoding of an access unit This is also a 33 bit number coded in three separate fields

ESCR The elemetary_stream_clock_reference (ESCR) is an optional 42 bit field coded as a 33 bit base field with a 9 bit extension field It indicates the intended time of arrival of the byte containing the last bit of the base field at the input of the system target decoder when present in PES Stream

ESCR_rate The elementary_stream_rate field is a positive integer specifying the rate at which the system target decoder receives bytes of the PES packet in the case of PES stream This field is valid in the PES packet in which it is included and in

subsequent PES packets of the ame PES stı am untıl a n w ES_rate field s e ıco ınteıe l The vılue of the ES_ ıte ıs measured ın unıts of 50 bytes/second rounded up vıı ds

DSM_trıck_mod This s ın 8 bıt f eld ındicatıı g the nature of the ınformatıon encoded This field ıs further partıtıoned as follo vs The field ıs further partıtıoned ıs follows

tıı k_mod _ ontıol (3 bıts)

fı l l_ıd (? bıts)

ıntı a_slıc _ıefı esh (1 bıt) and

fı equency_tı uncatıon (2 bıts)

tı ıck_mo le_ ontrol It ındıcates nature of the DSM Mode

000 Fast Forwıı d

001 Slow Motıon

010 Fıeeze Frame

011 Fast r verse

1xx Reserved

field_ıd This ıdentıfier ıs valıd ınterlıced pıctures only and describes how the current frame ıs to be dısplıyed

00 Dısplıy field 1 only

01 Dısplay field 2 only

10 Dısplıy complete frame

11 Reserved

ıntra_slıce_refresh This field ındıcates that each pıcture ıs composed of ıntra slıces with possıble gaps between them The decoder should replace the mıssın slıces by repeatın the collocıted sıtes from the prevıously decoded pıcture

fr quency_truı catıon This field ındıcates the selectıon of coefficients from the DSM

00 only DC coefficıents aı e sent

01 The first thıee coefficıents ın scan order on average

10 The first sıx coefficıents ın scan order on average

This field ıs for ınfoı matıon purposes only At tımes more than the specıfied number of coefficıents mıy be sent At other tımes less than the specıfıed number of coefficıents mıy be sent

PES Extcns Flags

PES p at d t fl	p k h d f ld fl g	p gram pa k t q u t fl g	STD B ff fl	R rv d	PES xt f ld fl

The PES header can contaın additıonal fla s ıf the PES Extensıon Flag ıs set These fla s ıre transmıtted ın a one byte data field as shown above The fla s ındıcate whether further extensıon to the PES header exıst In each case the flag ıs set to 1 ıf the header field ıs pıesent

PES private data flag A 1 bıt flag when set to 1 ındıcates that the PES packet headeı contaıns prıvıte datı

packet header field fla A 1 bıt fla when set to 1 ındıcates that an ISO/IEC 11172 pack header or an ISO/IEC 13818 Pro ram Stream pack header ıs stored ın this PES packet header If this field ıs ın a PES packet that ıs contaıned ın Proıram Stıeam then this field shall be set to 0 In a TS when set to a value of 0 ıt ındıcıtes that no pack heıder ıs present ın the PES header

pio ram pack t s qu nce counter flag A 1 bit flag when set to 1 ndicates that this fi ld is piesent in this PES pa ket

STD bi ff r fla A 1 bit flag when set to 1 indicates that the STD_buff r_scal and STD_buttei_size are available in the PES packet header

PES ext nsion fild fla This is a 1 bit tield vl en set to 1 indicates the presence of the I ES_extension_field

PES_private_data This is a 16 byte field which contains private data This data combin d with the fields before and after shall not emulate the packet_stait_code_piefix (0x000001)

pa k_field_l ngth This is a 8 bit field which indicates the length in bytes of the pack_header_field()

pro ram_packet_sequ nce_counter This is an 87 bit field It is an optional cou ter that inciements with each successive PES packet in progra n multiplex This allo vs an application to retiieve the original PES packet sequence of Program Stream This countei will wrap around to 0 after its maximum value

stuffing_byte This is a fixed 8 bit value equal to 1111 1111 that can be inserted by the encodei for example to met the requirements of the digital storage medium It is discauded by the decodei No more than ? stuffing bytes shall be present in a PES packet header

STD_buffer_scal (Program Stream only) This is a 1 bit field that indicates the scaling factor used to interpret the subsequent STD_buffer_size field If the preced ng stream_id indicates an audio stream STD_buffer_scale shall have the value 0 If the pieceding stream_id indicates a video stream this shall have a value 1 For all other stream tvpes the value may be either 1 or 0

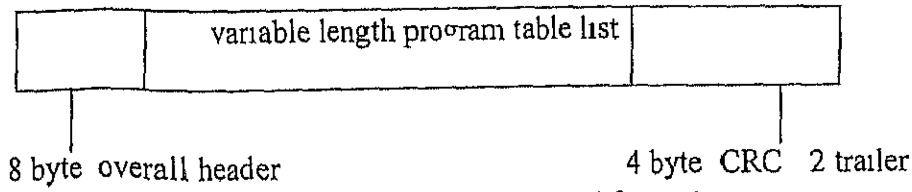
STD_buffer_size (Progiam Stream only) This is a 13 bit unsigned integer definin the size of the input buffer in STD If STD_buffer_scale has the value 0 then the buffer_size is measures the buffer size in units of 128 bytes If STD_buffer_scale has the value 1 then the buffei_size measures the buffer size in units of 1024 bytes

PES_extension_field_length This 7 bit field specifies the length in bytes of the data followin this in the PES_extension_tield

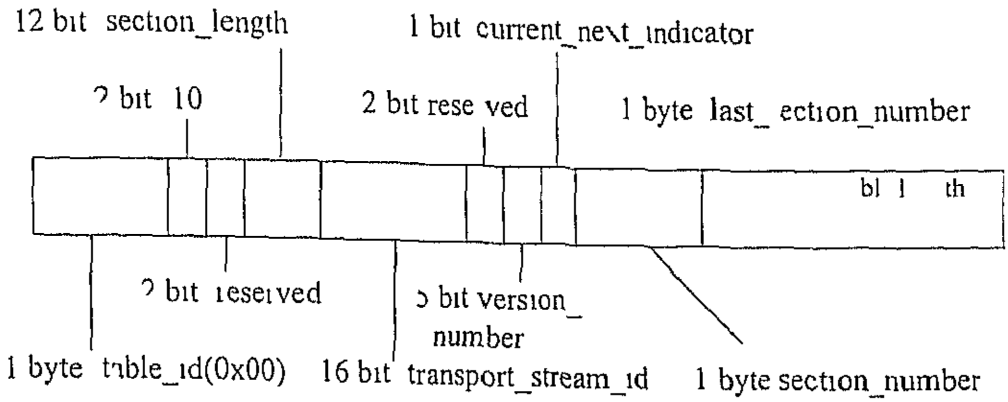
PES_packet_data_byte PES_packet_data_bytes shall be contiguous bytes of data fiom the elementary stream indicated by the packet s stream_id or PID The byte order of the elementary stieam shall be preserved

paddin _byte This is a fixed 8 bit value equal to 1111 1111 that can be inserted by the encoder to meet the requirements of DSM It is discarded by the decoder

Pro ram Association Segment and Table Header Formats



program_association_segment format



program_association_table field_length_header

Semantic definition of fields in Program Association segment header

pointer_field This is an 8 field whose presence in the beginning of the payload portion of the TS packet indicates that the payload contains program association table. The value of this 8 bit field indicates the number of bytes immediately following the pointer_field until the first segment that is present in the payload of the TS packet. When at least one section begins in a given TS packet then the payload_unit_start_indicator shall be set to 1 and the first byte of the payload that TS packet shall contain the pointer.

table_id This is a 1 byte field which is present commonly in program association table header, program map table header and conditional access table header and whose value depends on the table in which it is being used.

value	description
0x00	program association table segment
0x01	conditional access table segment
0x02	program map table segment
0x03 0x3F	reserved
0x40 0xFE	user defined
0xFF	forbidden

Table B 7 table id assignment values

section_length This is a twelve bit field the first two bits of which shall be 00. It specifies the number of bytes of the section starting immediately following the section_length field and including CRC.

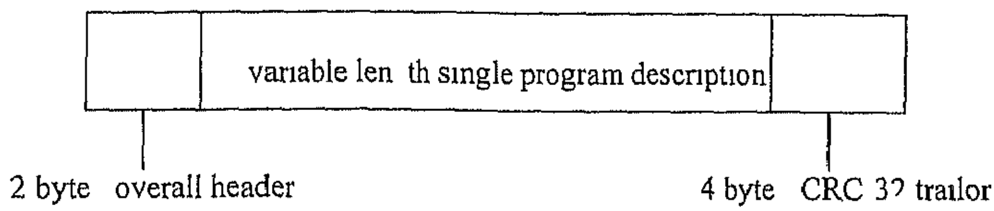
transport_stream_id This is a 16 bit field which serves as a label to identify this TS from any other multiplex within a network. Its value is defined by the user.

version_number This 5 bit field is the version number of the whole program association table. The version number shall be incremented by 1 whenever the definition of the Program Association Table changes. Upon reaching the value 31 it wraps around to 0. When the current_next_indicator is set to 1 then the version_number shall be that of the currently applicable program association table. When the current_next_indicator is set to 0 then the version_number shall be that of the next applicable program association table.

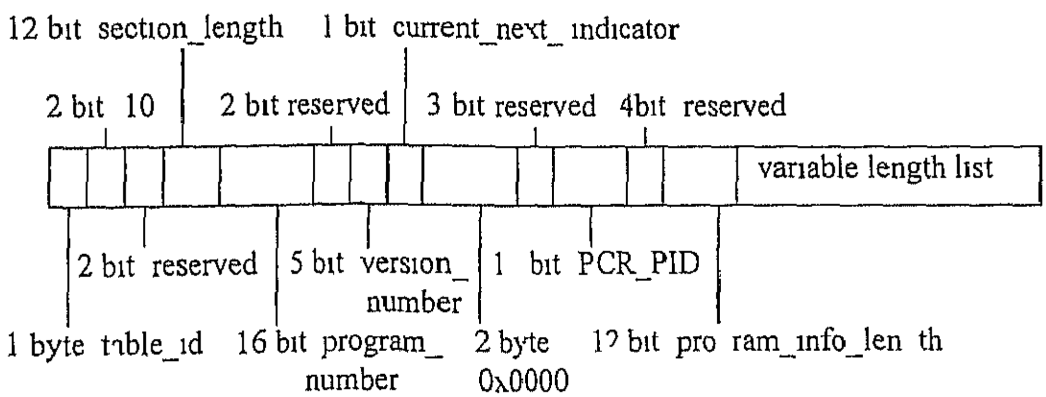
current_next_indicator A 1 bit indicator which when set to 1 indicates that the program association table is sent is currently applicable. When the bit is set to 0 it indicates that the table sent is not yet applicable and shall be the next table to become valid.

section_number This 8 bit field gives the number of this section The section_numbe of the first section in the program association table shall be 0x00 It shall be incremented by 1 with each additional section in the program association table
last_section_number This 8 bit field specifies the number of the last section of the complete program association table
variable length fields
program_number This is a 16 bit field It specifies the program to which the *program_map_PID* is applicable If this is set to 0x0000 then the following PID reference shall be the network PID For all other cases the value of this field is user defined This field shall not take any single value more than once within one version of the program association table
network_PID Network_PID is a 13 bit field specifying the PID of the TS packet which shall contain the Network Information Table The value of the network_PID field is defined by the user but shall not take values reserved for other purposes The presence of the network_PID is optional
program_map_PID This is a 13 bit field specifying the PID of the TS packet which shall contain the program_map_section applicable for the program as specified by the program_number No program_number shall have more than one program_map_PID assignment The value of the program_map_PID is defined by the user but shall not take the values reserved for other purposes

Program Map Table Details



program map section format



program_map_section fixed_length_header

Semantic definition of fields in TS program map section

table_id This will always be set to 0x02
section_length This is a twelve bit field the first two bits of which shall be 00 It specifies the number of bytes of the section startin immediately following the section_length field and includin CRC

pro ram_number This is a 16 bit field It specifies the program to which the pro ram_map_PID is applicabl One pro ram definition shall be carried within only one progr m_m p_section So program defin tion is never longer than 1016 bytes
v rsion_numbe Its function is same as that in p ogram ssocit on table
current_next_indicator Its fun tion is also identical to that of in pro_ram association table
PCR_PID This is a 13 bit field indicating the PID of the TS packet which shall cont in the PCP fiel ls valid for the progam specified by program_number If no PCR is associated with a program definition fo private streams then this field shall take the value of 0x1FFF
pro ram_info_len th This is a twelve bit field the first two bits of which shall be 00 It specifies the number of the descriptors immediately followi g this field
stream_type This is an 8 bit field specifying the type of elementary stream or payload carried within the packets with the PID whose value is specified by the elementary _PID The values of stream_type are specified in the following table

Value	Description
0x00	reserved
0x01	MPEG 1 video
0x02	MPEG 2 video
0x03	MPEG 1 audio
0x04	MPEG 2 audio
0x05	MPEG 2 private sections
0x06	MPEG 2 PES packets containing private data
0x07	ISO/IEC 13522 MHEG
0x08	ISO/IEC 13818 DSM CC
0X09	MPEG 2 private data
0x6A 0x7F	MPEG 2 reserved
0x48 0xFF	user defined

Table B 8 stream type assignment table

elementary_PID This is a 13 bit field specifying the PID of the Transport packets which carry the associated elementary stream or payload
ES_info_len th This is a twelve bit field. the first two bits of which shall be 00 It specifies the number of bytes of the descriptors of the associated elementary stream immediately following the this field

Appendix C
The DVB Standards

The DVB P oject Office has so far published the tollowin standards as European Telecommunication Standards Institute (ETSI) standards

DVB S Di ital bioadcasting systems for television sound nd data services Framing structure channel coding and modulation for 11/12 Ghz satellite services ETS 300 421 December 1994
The modem standard for satellite broadcasts with various data rates BW requirements and error correction capabilities

DVB C Di ital bioadcastin systems for television sound and data services Framing structure channel codin and modulation for cable systems ETS 300 429 December 1994
The modem standard for cable broadcasts with various data rates levels of noise immunity and BW requirements

DVB CS Digital broadcasting systems for television sound and data services Satellite Master Antenna Television (SMATV) distribution systems ETS 473 May 1995
Description of the alternative ways in which a community sat antenna installation head end could operate

DVB SI Digital broadcasting systems for television sound and data services Specification for Service Information (SI) in Di ital Video Broadcastin (DVB) systems ETS 300 468 October 1995
Electronic program guide and automatic tunin and VCR control information broadcasted in DVB data streams

DVB TXT Digital broadcasting systems for television sound and data services Specification for conveying ITU R System B Teletext in Digital Video Broadcastin (DVB) bitstreams ETS 300 472 May 1995
MPEG 2 encapsulation for the European analog teletext data

DVB CI Common Interface Specification for Conditional Access and other Digital Video Broadcasting Decoder Application European Standard prEN 50221 Draft D 1996 04 23
PCMCIA slot that will allow to add proprietary access control and other extensions

The DVB S standard has now also been included in ITU R recommendations Further DVB standards for terrestrial digital broadcast (DVB T) subtitlin MMDS and interactive TV are under preparation

In addition two ETSI Technical Reports (ETR) have been published that are not formal standards but form important guidelines for systems implementors

ETR 154 Digital broadcasting systems for television Implementation guidelines for the use of MPEG 2 systems Video and audio in satellite and cable broadcasting applications ETSI Technical Report draft ETR 154 1994 11
The MPEG_2 standard ISO/IEC 13818 specifies a very large number of system parameters and optional features This text specifies many MPEG minimum parameter ranges and options which every DVB receiver is supposed to support

ETR 211 Digital broadcasting systems for television Implementation guidelines for the use of MPEG 2 systems Guideline on implementation and usage of service information ETSI Technical Report final draft ETR 211 1996 02 12
This text provides many important details for implementing the DVB SI standard

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